

**WHAT HOLDS YOUR ATTENTION? THE NEURAL EFFECTS OF MEMORY ON
ATTENTION**

Emily Leonard Parks

A thesis submitted to the faculty of the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Masters of Arts in the Department of Psychology.

Chapel Hill
2009

Approved by:

Joseph Hopfinger

Charlotte Boettiger

Kelly Giovanello

ABSTRACT

EMILY LEONARD PARKS: What holds your attention? The neural effects of memory on attention

(Under the direction of Joseph Hopfinger)

The allocation of attention, including the initial orienting and the subsequent dwell-time, is affected by several bottom-up and top-down factors. How item-memory affects these processes, however, remains unclear. In four behavioral experiments, we investigated whether item-memory affects attentional dwell time by using a modified version of the attentional blink (AB) paradigm. Our results revealed that the AB was significantly affected by memory-status (novel versus old), but critically this effect depended on the ongoing memory context (Parks & Hopfinger, 2008). To directly examine the neural effects of memory and memory context on attentional allocation, we recorded event-related potentials (ERPs) while subjects performed a modified cuing paradigm. Our results revealed that memory significantly affects target processing at both early and late stages of analysis. Specifically, targets following memorially unique, “old” (previously studied) cues showed increased visual processing and faster reaction times compared to targets following non-unique cues. These data provide new evidence that memory affects attention at the neural level, and that this effect occurs at early visual processing levels (as indexed by the P1) and at higher order stages of processing (as indexed by the P300).

ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Joseph Hopfinger, for his guidance and persistent help throughout this project. I would also like to express my thanks to the other members of my committee, Dr. Charlotte Boettiger and Dr. Kelly Giovanello, for their time and helpful comments and suggestions.

TABLE OF CONTENTS

LIST OF FIGURES.....	vi
----------------------	----

Chapter

I.	PART 1: INTRODUCTION.....	1
II.	PART 2: INTRODUCTION.....	9
	Memory-related ERP Effects.....	11
	Attention-related ERP Effects.....	14
III.	PART 1: METHODS & RESULTS.....	17
	Experiment 2.....	17
	Participants.....	17
	Materials & Procedures.....	18
	Results.....	19
	Discussion.....	21
	Experiment 3.....	21
	Participants.....	22
	Materials & Procedures.....	22
	Results.....	22
	Discussion.....	24
	Experiment 4.....	25
	Participants.....	25
	Materials & Procedures.....	26

	Results & Discussion.....	26
IV.	PART 2: METHODS & RESULTS.....	31
	Experiment 5.....	32
	Participants.....	32
	Materials & Procedures.....	32
	Results & Discussion.....	34
	Experiment 6.....	37
	Hypotheses: Early Visual Components.....	37
	Hypotheses: Predicted Behavioral & Neural Effects of Memory on Attention.....	39
	Participants.....	40
	Materials & Procedures.....	41
	Recording & Analysis.....	42
	Behavioral Results: the memorial cues.....	43
	ERP Results: the memorial cues.....	43
	Discussion: the memorial cues.....	47
	Behavioral Results: the peripheral targets.....	47
	ERP Results & Discussion: the peripheral targets.....	49
V.	GENERAL DISCUSSION.....	54
	REFERENCES.....	63

LIST OF FIGURES

Figure

1.	Figure 1: T2 Accuracy (Experiment 1).....	4
2.	Example Stimuli.....	17
3.	Figure 2: T2 Accuracy (Experiment 2).....	20
4.	Figure 3: T2 Accuracy (Experiment 3).....	23
5.	Figure 4: T2 Accuracy (Experiment 4).....	27
6.	Design: Experiment 5.....	34
7.	Figure 5: Reaction Times to Targets (Experiment 5).....	36
8.	Design: Experiment 6.....	42
9.	Figure 6: ERPs to Memorial Cues, the parietal old/new effect.....	45
10.	Figure 7: ERPs to Memorial Cues, the late context effect.....	46
11.	Figure 8: ERPs to Peripheral Targets, the P1.....	50
12.	Figure 9: ERPs to Peripheral Targets, the P300.....	52

CHAPTER 1

PART 1: INTRODUCTION

The allocation of attention is affected by several factors, including bottom-up, reflexive capture toward stimuli that are highly salient in their physical features, and top-down voluntary orienting toward task relevant stimuli (Berger, Henik, & Rafal, 2005; Cheal & Lyon, 1991; Hopfinger & West, 2006; Jonides, 1981; Müller & Rabbitt, 1989; Posner & Cohen, 1984). More recent work has highlighted the effects of higher-order factors on attention, such as orienting toward the location of another person's gaze, toward emotional stimuli, and toward items being actively held in working memory (de Fockert, Rees, Frith, & Lavie, 2001; Fox, Russo, Bowles, & Dutton, 2001; Langton & Bruce, 1999; Ohman, Flykt, & Esteves, 2001; Smith, Most, Newsome, & Zald, 2006). The role of memory in the allocation of attention, however, remains unclear. Previous studies have shown that memory affects the initial capture of attention, although the results have been inconsistent regarding if it is the old or new item that captures attention. For example, some studies have found evidence for attentional capture to a novel word compared to previously studied words (Johnston, Hawley, Plewe, Elliott, & DeWitt, 1990; Wang, Cavanagh, & Green, 1994), whereas others have found evidence that a familiar word captures attention relative to a novel non-word (Christie & Klein, 1995). Despite different experimental paradigms and stimuli, and a different pattern of results, these previous studies suggest that item-memory does influence the initial capture or attraction of attention. In addition, recent evidence suggests that item-memory not only

affects this initial capture of attention, but also affects how long attention dwells or is held by an item. Exploring both of these mechanisms (the initial capture and the later hold of attention) provides a more comprehensive understanding of memory's effects on attention. Indeed, the holding of attention may be even more important than the initial orienting in affecting cognition and subsequent actions. Using eye-tracking as a means to examine both attentional capture and attentional hold, Chanon & Hopfinger (2008) recently found that fixations during scene-viewing were more frequent, and critically, lasted for a longer duration on "old" (previously studied) items versus "new" (never before seen) items. These results were found regardless of self-reported strategies, suggesting that item-memory may have an involuntary effect on attentional dwell time.

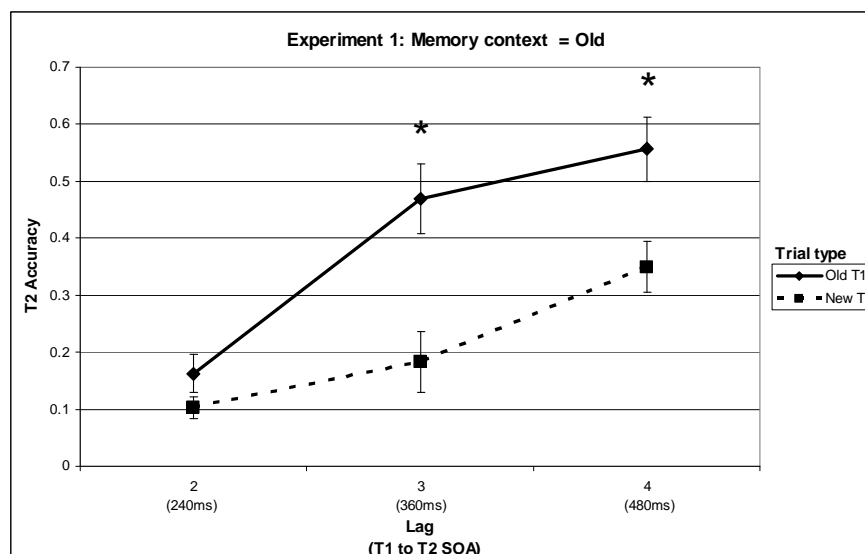
In the previous eye-tracking study, however, there was no immediate cost to dwelling longer on an item, and therefore it's unclear how strong or automatic this effect may be. To address this issue, Parks & Hopfinger (2008) utilized a different, well-established method for quantifying the temporal allocation of attention: the "attentional blink" (AB) paradigm. In this paradigm, there is a significant cost for increasingly long dwell times on the initial target, and therefore the automaticity of the effects of memory on attention can be measured. The AB refers to the finding that the correct identification of one target in a rapid serial visual presentation (RSVP) stream causes a marked impairment for detecting a second target (T2) presented shortly (~200-500 ms) after the onset of the first target (T1) (Broadbent & Broadbent, 1987; Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992). Evidence suggests this effect occurs at a postperceptual phase of T2 processing (Giesbrecht & Di Lollo, 1998; Vogel & Luck, 2002; Vogel, Luck, & Shapiro, 1998). One theory has proposed that, as limited attentional resources are absorbed in T1 processing, the consolidation of T2 into

memory is prevented (Chun & Potter, 1995). Further support for this theory comes from electrophysiological work finding that the T2-elicited P300, an ERP component related to the context updating of working memory, is suppressed during the AB, while earlier perceptual-based components are not (Vogel & Luck, 1998). Thus, according to this view, the T2 is perceived during the AB, but it cannot be fully consolidated and thus reported (Jolicoeur & Dell'Acqua, 2000). Therefore, although the AB is caused by the presence of T1, it is at T2 where the blink's measurable effects are manifested. Thus, the blink provides an excellent tool for measuring the effects of memory on attention. Of particular interest here was whether or not individual item-memory would influence the degree of attentional holding on that item. Specifically, using a modified AB paradigm, we manipulated the memory-status of the first target (T1) (while keeping the distracters "old") to investigate whether the presence and duration of the blink differs when old versus new items are the T1 (referred to here as Experiment 1). Before the experimental phase, participants performed an encoding task in which they had to make semantic judgments about a set of pictures in order to produce strong, robust memory traces (thus, creating a set of "old", previously studied, items for the AB phase) (c.f., Craik & Tulving, 1975). Following the encoding phase, participants performed the AB task described above. The experiment followed a typical procedure utilized in AB studies in which participants identified both T1 and T2 at the end of each trial (Chun & Potter, 1995; Giesbrecht & Di Lillo, 1998; Keil & Ihssen, 2004; Olson, Chun, & Anderson, 2001; Olivers & Nieuwenhuis, 2006; Raymond et al, 1992). A total of 240 sequences were presented, with 40 trials of each combination of memory-status and lag.

Critically, the results revealed new evidence that the memory-status of an item significantly affects the temporal allocation of attention, as the AB was extended when T1

was a “new item” (not seen previously in the experiment) as compared to an “old item” (previously studied). This delay in the recovery of the AB demonstrates that the attentional dwell time on T1 was significantly lengthened when T1 was a “new” item versus an “old” item. These results suggest that memory plays a significant role in the duration and temporal allocation of attention; specifically, that novel items increased the length of attentional hold, as compared to familiar items (Parks & Hopfinger, 2008; See Figure 1 below).

FIGURE 1: T2 Accuracy (Experiment 1)



SOA = stimulus onset asynchrony between T1 and T2

* denotes significance after B-H correction for multiple comparisons (Benjamini & Hochberg, 1995).

Although a robust effect was found suggesting that novel items hold attention, it is possible that this effect was at least partially due to two additional factors: the task utilized and the memory-status of the distractor stream (the non-target stimuli). In regards to the task (to identify T1 and T2 by name), the extended hold found for new items may have been related to differences in the time required to generate names for “old” versus “new” items.

Previously, it has been shown that the naming of an item is improved by prior experience with that item (e.g., Tulving & Schacter, 1990). In regards to Experiment 1, participants may have displayed a larger and prolonged AB because more time was required to generate a name for a new T1 as compared to an old T1. To remove this potential confound, we proposed a follow-up study (Experiment 2) in which the item pictures previously used as stimuli in Experiment 1 were replaced with abstract line-drawings. These abstract line-drawings were designed to minimize verbal processing; thus, reducing any possible effects resulting from differences in the time to generate names for old versus new items. This manipulation in stimuli led to several critical changes in the original experiment, including the timing and the task used. Specifically, because these abstract stimuli are more difficult to process, both the duration of the stimuli and the interstimulus interval between them was increased. In addition, the identification task previously utilized was replaced by a task that was not dependent on the naming of items (See Methods section for further details.). Overall, the goal of Experiment 2 was to replicate the findings of Experiment 1 (longer AB following new items, when context is old) using stimuli designed to limit verbal processing, thus ruling out the possibility of task effects.

In addition to the task effects, an important remaining issue lay in determining the quality of the novel item that led to its increased hold on attention. The results of Experiment 1 (and later Experiment 2) suggest that new items may hold attention longer because they've never been viewed before. However, the new items also had a unique memory-status relative to the ongoing context, as all the distractors were old. Recent work has supported this notion that it is not necessarily the item-memory strength *per se*, but rather its memorial uniqueness (relative to current context) that affects attentional allocation. For example, Diliberto,

Altarriba, & Neill investigated the initial orienting of attention and found that attention was involuntarily captured by the one word out of four simultaneously presented words that was unique in its memory (novel vs. familiar) (2000). While that study showed the importance of uniqueness in the initial capture of attention, attentional dwell time and memory context across time were not investigated.

Evidence that memorial uniqueness affects attention has also come from eye-tracking studies. For example, Ryan, Althoff, Whithlow, & Cohen (2000) investigated the influence of relational memory (memory between items) on attention. Participants viewed familiar scenes in which one region of the scene was manipulated (e.g., insertion of an item). These manipulations within old scenes increased attentional allocation to the one location that was “new” (i.e., modified), demonstrating the impact of relational memory on attention, but also demonstrating the effect of memorial uniqueness on attention. Additionally, the eye-tracking study by Chanon and Hopfinger mentioned previously also demonstrated the influence of item-memory and context on attention (2008). This study demonstrated that when viewing “new” scenes, participants looked more often and for longer durations at “old” items compared to “new” items. Again, it was the memorially unique item that captured and held attention. Overall, both of these eye-tracking studies support the idea that the effects of memory on attention are influenced by the interaction of item-memory and memory context.

The results of Experiment 1 originally suggested that new items may hold attention longer because they’ve never been viewed before (assuming that the effects of naming differences are removed by Experiment 2). In other words, the observed effect was attributed to the individual memory-status of T1. However, in that paradigm, the new item also had a unique memory-status relative to the ongoing context, as all the distractors were old. Based

on the literature described above, the finding that the new item led to its increased hold on attention may not be due to the novelty of T1, but instead may be linked to T1's individual memory-status compared to that of the distractors. To test whether it was the newness of the item or the memorial uniqueness that caused the protracted AB, we conducted an additional experiment (Experiment 3) in which the memory context was reversed by using new items as distractors instead of old items. Thus, "old" T1s were unique relative to ongoing context, contrary to Experiments 1 and 2, where "new" items were unique. If the attentional effects observed in Experiments 1 and 2 were solely due to the "newness" of T1, then the memorial context should not matter, and new items should again produce a protracted AB. However, if these effects are dependent on the memorial context, then Experiment 3 should display opposite results from Experiments 1 and 2 – specifically, old T1's (among new distractors) should cause a longer AB as compared to new T1's.

If Experiment 3 finds that the AB is extended when T1 is memorially unique, this will provide additional evidence that memorial uniqueness significantly affects attention. However, the possibility would still exist that the effect could be driven by the relation between T1 and T2 (i.e. memory priming), as opposed to the relation between T1 and the distractors (i.e., memory context). Recent work has demonstrated that T2 performance is worse when T1 and T2 come from different categories (e.g. letter vs. digit) compared to when both come from the same category (collapsed across type of distractor category) (Juola, Botella, & Palacios, 2004). To test whether our effects are driven by the ongoing memorial context set up by the distractors (as will be demonstrated in Experiment 3) or by a mismatch between T1 and T2, we conducted Experiment 4. This experiment was similar to Experiment

2 (wherein distractors and T2 were always “new”), except that here T2 was always “old,” and thus never matched the distractors.

Thus, the specifics goals of Part 1 were as follows:

- I. To reduce possible effects resulting from differences in the time required to generate names for “old” versus “new” items through the use of abstract line-drawings that minimize verbal processing (Experiment 2).
- II. To determine whether the effects of item-memory on attentional allocation were based on an item’s memorial strength *per se*, or rather, are based on an item’s memorial uniqueness relative to current context (Experiment 3).
- III. To rule out the possibility that the relationship between T1 and T2 (through memorial priming effects) was driving the results of Experiments 1-3, as opposed to the relationship between T1 and the distractors (through memorial context effects) (Experiment 4).

These goals were accomplished through Experiments 2, 3, and 4.

CHAPTER 2

PART 2: INTRODUCTION

Part 1 of this study utilized behavioral methods to investigate the effects of memory and particularly memory context on attention, finding that (as is later discussed) items unique in memory held attention longer than memorially non-unique items. However, much remains unclear concerning the neural underpinnings of this effect. While a great deal of electrophysiological work has been conducted on the cognitive systems of memory and attention individually, little is known concerning their interaction within the brain. Classically, memory and attention have each been studied at the neural level through the use of varying paradigms. For example, one means of studying recognition memory has been to examine the ERPs elicited by correctly classified old (previously studied) items as compared to correctly classified new (never before seen) items. Further, attention has been studied through cuing paradigms in which a cue (an arrow pointing left or right) voluntarily orients one's attention to a spatial location where a target may appear, leading to early visual processing enhancements to targets at that peripheral location (Mangun & Hillyard, 1991). However, of particular interest here is the neural activities related to the influence of memory and memory-context on attention, which to our knowledge has never been investigated. In order to examine this relationship, we proposed the use of a new paradigm, that combines the two paradigms described above, which are typically utilized to study memory and attention individually. We chose not to use the AB paradigm in conjunction with ERPs for several reasons. First, the rapid presentation of stimuli required for the AB paradigm leads to overlap

in the evoked potentials of the stimuli presented within the stream. Typically, this overlap can be removed through the use of a variable stimulus presentation; however, such a manipulation can change the inherent nature of the blink, and therefore, is not appropriate. While some studies have attempted to isolate T2 through the use of “blank” trials (T2s specifically) (Sergent, et al, 2005), no paradigm has been developed to isolate the ERPs to T1, the stimulus of interest here. In addition to this methodological difficulty, we were interested in memory-related ERPs which occur much later in time. Using the RSVP necessary for the AB paradigm, multiple stimuli would have been presented by the time that a memory-related component was evoked, and it would be impossible to distinguish which of many stimuli had produced a particular neural effect. Based on these limitations related to stimulus overlap problems, we chose to use a more standard attentional paradigm that has been commonly used to study attention through the use of ERPs (both in and outside our lab). Specifically, the voluntary arrow cue used in the cuing paradigm (described above) was replaced with pictures of items which vary in their memory-status. Therefore, peripheral targets were preceded not by a cue directly orienting attention, but rather by an old (previously studied) or new (never before seen) picture, now referred to as a “memory cue.” This memory cue was not predictive of the target location, but allowed us to examine how memory-status affects attention, as indexed through the neural processing of targets which follow old or new memory cues. Because we were interested not only in the effects of memory-status, but also in those of memory context on attention, we also manipulated the probability of old and new items. Specifically, we compared the neural processing of targets following old memorially unique cues to that of targets following memorially non-unique cues. Before discussing

further details of this new paradigm, it is first necessary to provide further background regarding the ERP components affected by memory and by attention.

Again, because we are most interested in the effect of memory on the *temporal* allocation of attention, we proposed the use of event-related potentials (ERPs), which provide excellent temporal resolution. ERPs reflect voltage changes on the scalp that allow for a measurement of the processing of an event (i.e. a stimulus). They are represented as waveforms of positivities and negativities (peaks and troughs) whose averages reflect the temporal progression of the neural processing related to that event. Each of these peaks or troughs is considered to be an ERP component, defined by its polarity and temporal position within the ERP waveform. Many of these ERP components have been linked to specific functional processing through the evaluation of their amplitudes and latencies.

Of particular interest here was how memory's affect on attention influences stimulus processing, whether it be at early visual processing levels or at later higher order levels. Before evaluating the influence of this interaction, it is important to first understand how these two cognitive systems (memory and attention) individually affect stimulus processing. Our discussion will begin with the ERP effects of memory.

Memory-related ERP Effects

Different types of memory have been found to have distinct ERP correlates. Critical to this study is the identification of separate ERP components related to the processing of memory-status and the processing of memory context, respectively. In regards to memory-status, numerous ERP studies have revealed a pattern known as the parietal "old/new effect," in which correctly-judged studied items elicit more positive ERPs compared to correctly-

judged new items. This positive shift is maximal over the left parietal scalp between 500 and 800ms after stimulus onset and is traditionally suggested to be sensitive to, or reflect some aspect, of, recollection-driven recognition (Wilding & Rugg, 1996; Smith, 1993); the parietal old/new effect is not associated with the P300 component (Herron, Quayle, & Rugg, 2003). Additionally, the parietal old/new effect has been further characterized through the use of functional magnetic resonance imaging (fMRI), finding that studied items (as compared to new items) are associated with an increased neural response within several regions most consistently including: the inferior and superior parietal cortex, medial parietal cortex, posterior cingulate cortex, and prefrontal areas such as the bilateral anterior, right dorsolateral, and left ventrolateral cortex (Rugg & Henson, 2002; Herron, Henson, & Rugg, 2004). The anatomical overlap between the neural circuits engaged in the parietal old/new effect and those involved in attentional processing provide some of the first evidence for a functional link between memory and attention.

In addition to the parietal old/new effect, recent research has identified additional memory-related components which are dependent not on individual item-memory, but rather on the memorial context established between an item and the items surrounding it. By manipulating the ratio of old and new items in a test phase, the effects of memorial context can be investigated. Using ERP designs, it has been found that varying the old:new ratio (and thus the memory context) had no effect on the amplitude or the scalp distribution of the parietal old/new effect, despite informing the participants of this manipulation (Herron et al, 2003; Friedman & Johnson, 2000; Rugg & Allan, 2000). Based on the notion that the parietal old/new effect reflects recollection-driven recognition, this dissociation was considered evidence that the parietal old/new effect solely related to memory retrieval can be separated

from those related to other processes (i.e. detection of memorial uniqueness). Critically, this manipulation of the probability of old to new items led to the discovery of two distinct ERP components related to memory context. Specifically, Herron and colleagues (2003) found a late component (~800-1100ms) that demonstrated a greater positivity for low probability items (nouns that were memorially unique) than for items of either equal or high probability. This effect was more prominent for old items, however the scalp distribution of this “probability” or “context” effect (maximal over the midline and right posterior scalp) was significantly different from that of the parietal old/new effect, suggesting that these two components arise from at least partially distinct neural generators. In addition, both the time course and the topography of the context effect were found to be distinct from that of the P300. Overall, this study provided new evidence that the parietal old/new effect traditionally associated with successful episodic retrieval can be dissociated from a second, later component related to variables such as probability, or memorial context. Again, such findings suggest that these two components may reflect differing neural generators (Herron et al, 2003).

In order to localize these neural generators, Herron and colleagues employed the same paradigm mentioned above utilizing an event-related fMRI design. As expected, it was found that old/new effects within certain regions were not affected by variations in the old:new ratio, while other regions were strongly influenced by this manipulation. Specifically, greater activity was found in the bilateral inferior and medial parietal cortex, and the posterior cingulate by correctly judged old (as compared to new) items, regardless of the old:new ratio. In contrast, activity within the superior parietal cortex and several prefrontal areas (anterior, dorsolateral, and ventrolateral prefrontal cortex) depended on the old:new

ratio. Again, these data support a distinction between the parietal old/new effect and the memory context effects. Upon these findings, further analysis was conducted on the original ERP data of Herron and colleagues (2003), leading to the discovery of a second context-dependent ERP component. Specifically, around 1200ms after stimulus onset, a negative shift over frontal electrodes was found for memorially unique items, but not during equal probability conditions.

To summarize, distinct sets of memory-related ERP components have been identified: one reflecting recollection-driven recognition (parietal old/new effect) and two reflecting memorial context (late components identified by Herron et al). All of these components have been identified in paradigms employing a test phase involving the slow presentation of individual items. To our knowledge, no previous studies have investigated how these memory components are affected by the presence of an additional stimulus following the memory cue that does not vary in terms of its memory-status (i.e. a peripheral target). Although these memory effects are of interest, we are more primarily concerned with memory's affect on *attentional* processing. However, before discussing this topic, we must again first describe typical ERP effects found to be modulated solely by attention.

Attention-related ERP Effects

Many previous studies have demonstrated that voluntary attention influences stimulus processing at both early and late stages of analysis. Items which are voluntarily attended to, as compared to items that are unattended, have enhanced early visual processing as indexed by increased amplitudes in two extrastriate-generated components: the P1 (in discrimination and localization tasks) and the N1 (in discrimination tasks) (Heinze, Mangun, Burchert,

Hinrichs, Scholz, & Munte, 1994; Mangun, Hopfinger, Kussmaul, Fletcher, & Heinze, 1997; Hopfinger & Mangun, 1998; Mangun & Hillyard, 1991; Vogel & Luck, 2000). The P1 is a positive deflection peaking 80-130ms post stimulus onset and generated in the occipital cortex, and the N1 is a negative deflection composed of several subcomponents that peak 100-200ms post-stimulus. Appearing after these early sensory-driven components is a later component appearing 250-500ms post-stimulus, which has also been found to be modulated by attention. This higher order component, known as the P300, is interpreted as reflecting the contextual updating of working memory (Donchin & Coles, 1988). The latency of the P300 is influenced by the level of difficulty that is required to categorize two or more stimuli types and is considered to reflect stimulus evaluation time (Donchin & Coles, 1988). The amplitude of the P300 is modulated by the probability of a stimulus type. More specifically, rare items increase the amplitude of the P300, as compared to common items (Donchin & Coles, 1988). The amplitude of the P300 is also reduced for unattended stimuli (Mangun & Hillyard, 1995). In summary, by examining which ERP components are influenced by attention, the level of attention's effect on that stimulus processing can be determined. Modulations of the P1 and N1 reflect early effects on visual processing, while modulations of the P300 reflect later higher-order stimulus processing effects.

In summary, attention has been found to affect both early visual processing (i.e. the P1 and the N1) and later categorization processing (i.e. the P300) of visual stimuli. To our knowledge, no previous studies have investigated how attention (as seen through modulations of the P1, N1, and P300 to targets) is affected by memory at the neural level. Therefore, the goal of the current study was to examine the neural effects of memory and memory context on attention through the use of ERPs. First, a pilot behavioral study

(Experiment 5) was conducted to determine the stimulus presentation rate (more specifically, the optimal stimulus onset asynchrony between stimuli) in which the effects of memory on attention are largest. Then, the resulting stimulus rate was utilized in the design of Experiment 6. Importantly, Experiment 6 employed event-related potentials in order to examine the neural effects of memory on attention.

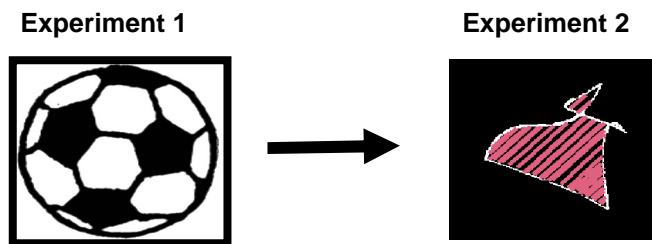
CHAPTER 3

PART 1: METHODS & RESULTS

Experiment 2

Experiment 1 revealed new evidence that the memory-status of an item affects attentional dwell time; specifically, that the AB is extended when T1 was a “new” item as compared to an “old” item. The goal of Experiment 2 was to minimize any potential effects seen in Experiment 1 related to differences in the time required to generate names for “old” versus “new” items. This was accomplished through the use of abstract line-drawings which were designed to limit verbal processing (Please see examples below).

Example Stimuli:



Participants

Seventeen undergraduates, ages 18-20 (13 female) and with 20/20 or corrected to 20/20 vision, from the University of North Carolina at Chapel Hill participated for course credit.

Materials & Procedure

Participants first completed three blocks of encoding. For stimuli, abstract shapes were extracted from a set of line-drawings designed by Slotnick and Schacter (2004) to limit verbal processing. Participants were instructed to study each line-drawing (average size $7.9^\circ \times 7.9^\circ$) in preparation for a later memory test. The stimuli were presented one at a time, and each block was self-paced. Thirty-six objects were studied; thirty of which were used in the subsequent AB trials (the same thirty for all subjects).

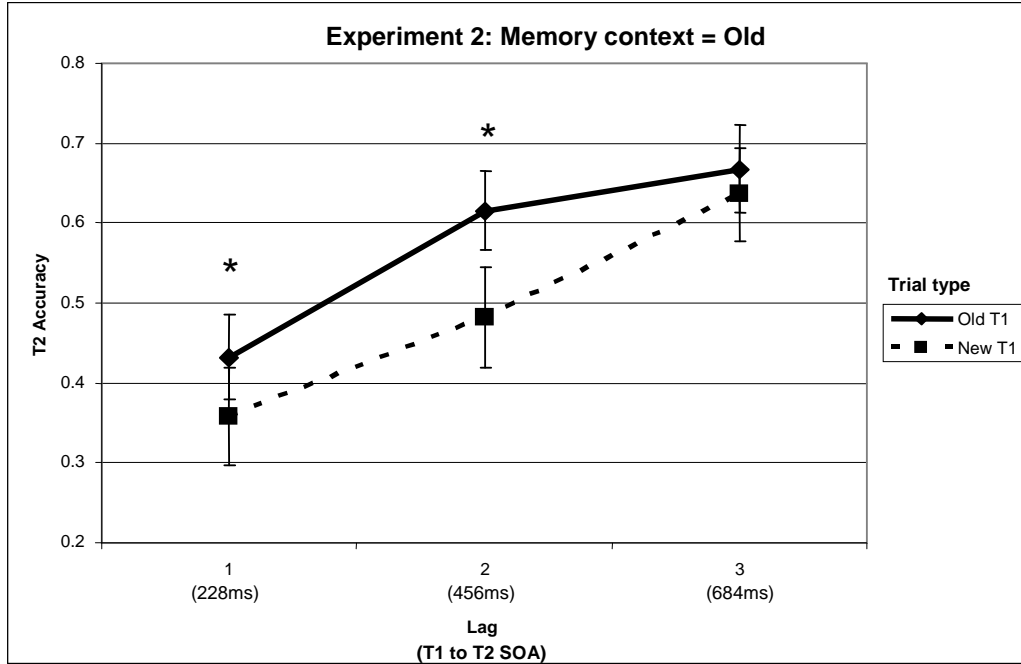
The AB trials were similar to Experiment 1, but with a few differences related to the change in stimuli. Like Experiment 1, new items were considered memorially unique among old distractors. Unlike Experiment 1, the stimuli used were not line-drawings of common items, but were instead abstract line-drawings with colored internal lines. The non-target stimuli were all old (previously studied) pictures, with a black background; T1 and T2 had gray backgrounds. T1 was equally likely to be an old or new item, and it appeared randomly at serial position 4 or 5. T2 consisted of only old items, and it randomly appeared 1, 2, or 3 positions after T1 (i.e., lag 1, 2, or 3). There were 10 items per stream, and each picture was displayed for 176ms with an ISI of 52ms (an increase as compared to Experiment 1 to reflect the increased stimulus processes difficulty of abstract items). Due to the increased duration and inclusion of an ISI, the lags here are not temporally equivalent to those in Experiment 1. Additionally, the original identification task used in Experiment 1 was no longer applicable and was replaced with tasks that were not dependent on naming. Specifically, at the end of each trial, participants made an old/new response to T1 and matched the color of T2 to a color on a 3x3 grid of color patches. There were 24 trials of each combination of memory-status and lag. Following the AB task, participants completed a recognition memory test.

Specifically, participants were asked to judge whether or not they had studied a particular item during the encoding phase.

Results

A two-way ANOVA was performed on T2 accuracy with the factors of T1 memory-status (old T1 or new T1) and lag (2, 3, or 4). Only trials in which T1 was correctly identified were included. For T2, the ANOVA revealed significant main effects of both memory-status [new: 0.585; old: 0.542; $F(1,16)=11.907$, $p=0.003$] and lag [lag 1: 0.424; lag 2: 0.593; lag 3: 0.664; $F(2,32)=17.176$, $p<0.001$], and an interaction between memory-status and lag that approached significance. Paired t-tests were also conducted on T2 accuracy and were corrected for multiple comparisons using the Benjamini & Hochberg (B-H) correction procedure (1995). At Lag 1, T2 accuracy was significantly worse for “new T1” trials ($M=0.358$; $SD=0.238$) compared to “old T1” trials ($M=0.433$; $SD=0.206$) ($t(16)=2.140$, $p=0.024$). This same significant effect was present, and was even larger, at Lag 2 (“new T1” trials: $M=0.482$, $SD=0.257$; “old T1” trials: $M=0.616$, $SD=0.194$; $t(16)=3.520$, $p=0.001$). At Lag 3, there were no longer any significant differences ($t(16)=1.026$, $p=0.160$) in T2 accuracy between “old T1” trials ($M=0.668$; $SD=0.226$), and “new T1” trials ($M=0.636$; $SD=0.247$). Despite the change in the stimuli and tasks, the findings of Experiment 2 replicated the key finding of Experiment 1: the AB was extended when T1 was a “new item” as compared to an “old item” when the memory context was “old items” (Figure 2).

FIGURE 2: T2 Accuracy (Experiment 2)



SOA = stimulus onset asynchrony between T1 and T2

* denotes significance after B-H correction for multiple comparisons (Benjamini & Hochberg, 1995).

Mean T1 accuracy was 77.9% with no significant effect of memory-status [$F(1,16)=1.692, p=0.212$]. A significant main effect of lag was found [$F(2,32)=7.770, p=0.002$], as was a significant interaction between memory-status and lag [$F(2,32)=7.439, p=0.002$]. However, paired t-tests revealed no significant differences in T1 accuracy between “old T1” and “new T1” at any lag. [Lag 1: $t(16)=-1.89, p=0.039$, not significant when corrected for multiple comparisons; Lag 2: $t(16)=-0.410, p=0.344$; Lag 3: $t(16)=-1.301, p=0.106$].

After the AB task, participants completed a recognition memory test for single objects (one-fourth new; one-fourth encountered in only the encoding phase; one-fourth encountered in the encoding and AB phases; one-fourth encountered only during the AB phase). Participants were asked whether or not they had studied the item during the encoding

phase. Overall, participants correctly judged 90.2% of the studied items as “studied,” with no differences between items seen or not seen in the AB phase. [Studied Only: $M=0.902$ ($SD=0.196$); Studied & used in AB phase: $M=0.902$ ($SD=0.167$); $t(16)=0.000$, $p=1.000$]. In addition, participants were highly accurate on judging items that were new as “not studied” ($M=0.902$; $SD=0.166$).

Discussion

The goal of this experiment was to remove any possible effects present in Experiment 1 that may have been related to differences in the time to generate names for old versus new items. This was accomplished by replacing the stimuli used in the original paradigm (line-drawings of items) with abstract stimuli designed to limit verbal processing. Despite the change in stimuli, the results of Experiment 2 replicated the findings of Experiment 1 (longer AB following new items, when context is old), suggesting that the observed findings were not confounded by naming effects.

Experiment 3

The results of Experiments 1 and 2 suggest that new items may hold attention longer because they’ve never been viewed before. However, the new item also had a unique memory-status relative to the ongoing context, as all the distractors were old. To test whether it was the newness of the item or the memorial uniqueness that caused the protracted AB, we conducted a third experiment in which the memory context was reversed by using “new” items (never before seen) as distractors instead of old items. Thus, “old” T1s were now unique relative to ongoing context, contrary to Experiments 1 and 2 where “new” items were

unique. If the attentional effects observed in Experiments 1 and 2 were solely due to the “newness” of T1, then the memorial context should have no effect, and new items should again produce a protracted AB. However, if these effects are dependent on the memorial context, then Experiment 3 should display opposite results from Experiments 1 and 2 – specifically, old T1’s should cause a longer AB compared to new T1’s.

Participants

Sixteen undergraduate students, ages 18-20 (10 female), from the University of North Carolina at Chapel Hill participated. Each participant had 20/20 or corrected to 20/20 vision and received course credit as compensation.

Materials & Procedure

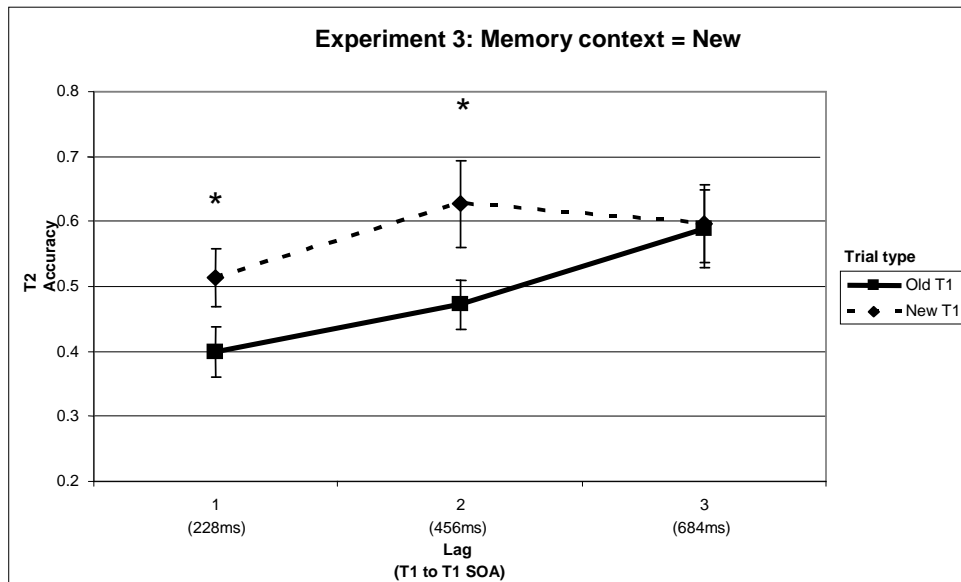
Stimuli and procedures were the same as in Experiment 2, except that the memory-status of the nontarget distractors and T2 was “new” instead of “old.” Therefore, “old” items were considered unique among “new” distractors.

Results

A two-way ANOVA and paired t-tests were conducted on T2 accuracy, as in Experiments 1 and 2. Only trials in which the T1 task was correctly completed were included. The ANOVA revealed significant main effects of both memory-status and lag. T2 accuracy was significantly reduced when T1 was an old item, compared to a new item [old: 0.493; new: 0.578 $F(1,15)=12.516, p=0.003$], and T2 accuracy increased with increasing lag [lag 1: 0.464; lag 2: 0.501; lag 3: 0.626; $F(2,30)=7.331, p=0.003$]. Finally, there was a significant

interaction between memory-status and lag [$F(2,30)=3.658, p=0.038$]. Paired t-tests were again corrected for multiple comparisons using the B-H correction procedure (1995). At Lag 1, T2 accuracy was significantly worse for “old T1” trials ($M=0.399; SD=0.176$) versus “new T1” trials ($M=0.514; SD=0.154$) ($t(15)=-3.46, p=0.002$). This difference was also significant, and even larger, at Lag 2 (“old T1” trials: $M=0.473; SD=0.267$; “new T1” trials: $M=0.627; SD=0.150; t(15)=-3.62, p=0.001$). At Lag 3, T2 accuracy was no longer different ($t(15)=-0.162, p=0.437$) between “old T1” ($M=0.589; SD=0.240$), and “new T1” trials ($M=0.597; SD=0.237$) (Figure 3).

FIGURE 3: T2 Accuracy (Experiment 3)



SOA = stimulus onset asynchrony between T1 and T2

* denotes significance after B-H correction for multiple comparisons (Benjamini & Hochberg, 1995).

Mean T1 accuracy was 83.2% with a significant effect of memory-status [new: 0.872; old: 0.798; $F(1,15)=21.152, p<0.001$]. No significant main effect of lag was found [lag 1:

0.790; lag 2: 0.799; lag 3: 0.808; $F(2,30)=0.370$, $p=0.694$], and no interaction between memory-status and lag was found [$F(2,30)=0.596$, $p=0.558$].

In the memory test, participants correctly judged 94.8% of the studied items as “studied,” and the additional exposure during the AB phase made no difference [Studied Only: $M=0.927$ ($SD=0.149$); Studied & used in AB phase: $M=0.969$ ($SD=0.067$); $t(15)=-1.000$, $p=0.333$]. In addition, participants correctly judged 93.8% of items that were new or seen only during the AB phase as “not studied,” with no differences between “new” items ($M=0.906$; $SD=0.211$) and those seen only during the AB phase [$M=0.969$; $SD=0.067$]; $t(15)=1.103$, $p=0.287$]. Thus, the initial encoding, not the subsequent exposure during the AB task, was the critical factor in establishing these memories.

Discussion

In direct contrast to Experiments 1 and 2, the current experiment found that the AB was extended when T1 was an “old item” as compared to a “new item.” Together, these data provide strong evidence that the effects of memory on attention here are not critically dependent on the particular memory-status of an item (old or new), but rather on the memorial uniqueness of an item relative to ongoing context. Overall, the results of Experiments 1, 2, and 3 provide new evidence for an aspect of attention that has not been well understood - the influence of item-memory on attentional allocation. Whereas previous work has emphasized the role of item-memory strength alone, the experiments here suggest that a broader view that also accounts for an item’s memorial context may be necessary.

The findings of Experiments 1-3 suggest that memorial context is driving the effect of memory on attention seen here. However, these experiments do not rule out one other

possible explanation: perhaps the effect here is driven by the relation between T1 and T2 (memory priming), as opposed to the relation between T1 and the distractors (i.e., memory context). To directly address this alternate explanation, we conducted Experiment 4 to test whether our effects are driven by the ongoing memorial context set up by the distractors or by a mismatch between the memory-status of T1 and T2.

Experiment 4

This experiment was identical to Experiment 3 (wherein distractors and T2 were always “new”), except that here T2 was always “old,” and thus never matched the distractors. If the attentional effects observed in Experiments 1-3 were due to the memory context of the distractor stream, then in the present experiment, “old T1’s” (being memorially unique relative to the distractors) should produce a protracted AB even though they match the memory-status of T2 (“old” T1; “old” T2). However, if our previous effects are dependent on the memorial similarity between T1 and T2, then a longer blink should be produced here when T1 and T2 do not match (“new” T1; “old” T2).

Participants

Twenty-four undergraduate students, ages 18-20 (17 female), from the University of North Carolina were recruited. One participant was excluded due to an apparent lack of encoding of the studied items (performance was at chance for identifying studied items as “old” and near chance for identifying unstudied items as “new”). Each participant had 20/20 or corrected to 20/20 vision and received course credit as compensation.

Materials & Procedure

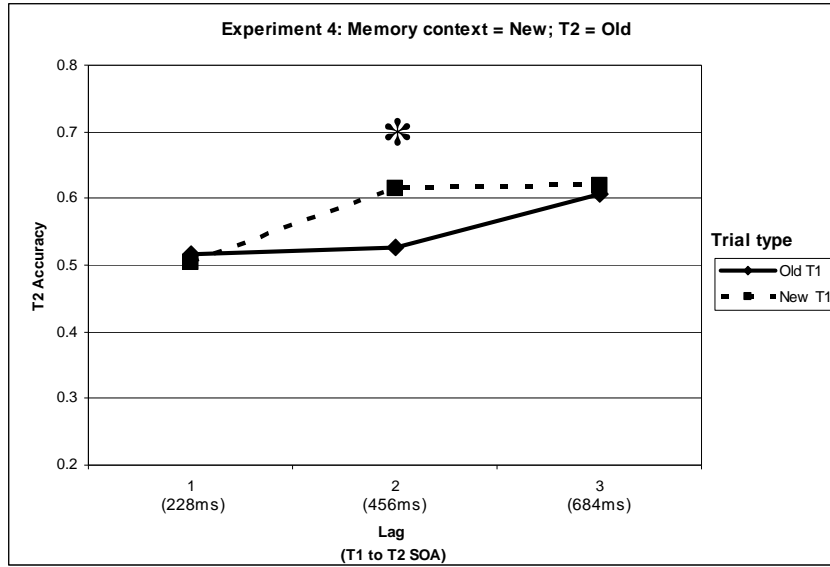
Stimuli and procedures were the same as in Experiment 3 (e.g., “new” distractors), except that the memory-status of T2 was always “old.”

Results & Discussion

A two-way ANOVA and paired t-tests were conducted on T2 accuracy (for trials wherein T1 was correctly identified). No main effect of memory-status was found new: 0.579; old: 0.550; $F(1,22)=1.870$, $p=0.185$, but there was a significant main effect of lag [lag 1: 0.510; lag 2: 0.571; lag 3: 0.613; $F(2,44)=6.412$, $p=0.004$], and the interaction between memory-status and lag approached significance [$F(2,44)=2.503$, $p=0.093$]. Paired t-tests were again corrected for multiple comparisons using the B-H correction procedure. At Lag 1, there was no difference between T2 accuracy for “old T1” trials ($M=0.517$; $SD=0.156$) versus “new T1” trials ($M=0.504$; $SD=0.194$) ($t(22)=0.415$, $p=0.341$). However, there was a significant difference between “old” and “new” T1 trials at Lag 2 (“old T1” trials: $M=0.527$; $SD=0.173$; “new T1” trials: $M=0.615$; $SD=0.149$; $t(22)=-2.23$, $p=0.018$). At Lag 3, T2 accuracy was no longer different ($t(22)=-0.397$, $p=0.348$) between “old T1” ($M=0.607$; $SD=0.144$), and “new T1” trials ($M=0.620$; $SD=0.127$). Overall, an extended blink was found when T1 was “old” among “new” distractors, despite the fact that “old” T1 stimuli matched the memory-status of the T2 stimuli (i.e., “old”). If the observed effects had been due to the relationship between T1 and T2, then “new T1’s” (being memorially different from “old T2’s”) should have produced a longer blink. However, memorially unique targets (“old T1’s”) led to a protracted blink here, providing further evidence that the effects

observed in the present set of experiments are driven by memory context (the relationship between T1 and the distractors) and not by memory priming between T1 and T2 (the relationship between T1 and T2) (Figure 4).

FIGURE 4: T2 Accuracy (Experiment 4)



SOA = stimulus onset asynchrony between T1 and T2

* denotes significance after B-H correction for multiple comparisons (Benjamini & Hochberg, 1995).

Mean T1 accuracy was 78.8% with a significant effect of memory-status [new: 0.837; old: 0.738; $F(1,22)=12.847$, $p=0.002$]. No significant main effect of lag was found [lag 1: 0.796; lag 2: 0.770; lag 3: 0.798; $F(2,44)=1.747$, $p=0.186$, n.s.]. A significant interaction between memory-status and lag was found [$F(2,44)=14.664$, $p<0.001$]; however, this interaction on T1 responses does not seem related to the T2 effect, since paired t-tests revealed that this interaction on *T1 responses* was driven by the lack of an effect at *lag 1* trials (old T1”: $M=0.798$; $SD=0.116$; “new T1”: $M=0.794$; $SD=0.154$; $t(22)=0.149$, $p=0.441$),

whereas the memory context effect on *T2 responses* occurred at a different lag (i.e. on *lag 2* trials).

For the recognition memory test, participants correctly judged 95.3% of the studied items as “studied,” and the additional exposure during the AB phase made no difference [Studied Only: $M=0.927(SD=0.131)$; Studied & used in AB phase: $M=0.978(SD=0.057)$; $t(22)=-2.07, p=0.024$, n.s. with B-H correction]. In addition, participants correctly judged 91.3% of items that were new or seen only during the AB phase as “not studied,” with no differences between “new” items ($M=0.913; SD=0.132$) and those seen only during the AB phase [$M=0.902; SD=0.206$; $t(22)=0.157, p=0.438$].

Overall, the goals of Part 1 were accomplished:

- I. Experiment 2 replicated the key finding of Experiment 1, finding that the AB was extended when T1 was a “new item” as compared to an “old item” (when the memory context was “old items”). Because Experiment 2 utilized abstract line-drawings that minimize verbal processing, it was concluded that the results seen in Experiment 1 were not due to differences in the time required to generate names for “old” versus “new” items.
- II. Contrary to Experiments 1 and 2, Experiment 3 demonstrated that the AB was protracted when T1 was an “old item” as compared to a “new item.” This was accomplished by reversing the memory context originally seen in Experiments 1 and 2. Based on this finding, it was concluded that it was not the newness of an item, but rather the memory uniqueness the item (an old item among new

distractors or a new item among old distractors) that significantly increased attentional dwell time as measured by an extended AB.

III. Experiment 4 provided direct evidence that the effects of memory on attention observed here (an increased AB following memorial unique) was indeed driven by memorial context, and not by memorial priming between T1 and T2.

In summary, Part 1 of this study provided new evidence for an aspect of attention that has not been well understood - the influence of item-memory on attentional allocation. Using the AB paradigm, we found that a T1 unique in memory-status (an old item among new distractors or a new item among old distractors) increased the duration of the AB. This effect was not dependent on the memory-status of T1 alone or on the relationship between T1 and T2, but was dependant on the memorial context (i.e., memory-status of surrounding distractors) (Parks & Hopfinger, 2008). One further consideration concerns whether the effect found here is specific to “memorial uniqueness,” or if it might apply to any general category difference, or in other words, any broad “uniqueness” unrelated to memory. However, the results of Part 1 (specifically, Experiment 4 of Part 1) in conjunction with another recent AB study suggest that the effect found here is indeed specific to memory. This study by Juola and colleagues (2004) parallels our current Experiment 4. While our stimuli varied in memory-status, those of Juola et al differed in their over-learned general categories (i.e., numbers and letters). Like our Experiment 4, the category of T1 was manipulated to be similar or different from the distractors, and the T2 category was always different from the distractors. Critically, their results found that the *non-unique* T1 led to an increased AB, whereas a unique T1 did not produce an AB (i.e., flat function across lags). Again, our study

found the opposite pattern: the *unique* T1 item produced an extended AB as compared to a non-unique item. Though these two studies were conducted for different purposes and utilized different timing, a comparison of these results suggests that the effects of memory (as seen in our experiments) seem to be distinct from those of general categories (as seen by Juola et al). In conclusion, our results provide a first step in establishing that item-memory uniqueness, determined through the interaction of item-memory strength and temporal memory context, plays a significant role in the temporal allocation of attention.

CHAPTER 4

PART 2: METHODS & RESULTS

Part 1 used behavioral methods to examine the effects of memory and memory context on attention. However, little is known concerning the neural underpinnings of these effects. The goal of Part 2 was to investigate the neural effects of memory, and particularly memory context, on attention using a modified cuing paradigm. In Experiments 5 and 6, 25% of the pictures were “old”, and 75% were “new”. Thus, “old” items were unique relative to the ongoing context. This particular memory context (where old items were unique) was selected to promote maximal dissociation between the parietal old/new effect and the later memory context effects.

First, a behavioral study (Experiment 5) was conducted to determine the optimal temporal range (specifically, the stimulus onset asynchrony between cues and targets) in which memory’s influence on attention was the largest. Once this time period was established, it was subsequently used (with modification, as will be discussed) in the cuing paradigm of Experiment 6, which additionally utilized event-related potentials. In this phase, a memorial context was established by centrally-located pictorial cues (i.e. memory context = new, when 75% of the cues are novel) as an unrelated attention task was performed in the periphery.

Experiment 5

Participants

Eight undergraduate students (5 female and 3 male) from the University of North Carolina at Chapel Hill were recruited to participate. Each participant had 20/20 or corrected to 20/20 vision and was compensated with course credit.

Materials & Procedure

Before performing the experimental task, participants completed three blocks of “encoding” in which they made judgments about isolated objects. The stimuli no longer consisted of abstract line-drawings as in Experiments 2, 3, and 4 of Part 1 (AB studies), but rather consisted of black and white line-drawings of objects similar to those used in Experiment 1. In Experiments 2, 3, and 4, object stimuli were not used in order to remove any potential confound related to naming effects. However, these experiments found that naming effects were not driving the observed attentional effects. Because the possibility of naming effects was discounted, and because line-drawings of actual objects inherently lead to stronger memory traces, Experiment 5 (and 6) utilized pictorial object stimuli as opposed to abstract line-drawings. Specifically, picture stimuli were black and white line-drawings of common items extracted from various libraries, including 174 from the library of Snodgrass and Vanderwart (1980). Several other sources were utilized to supplement the Snodgrass and Vanderwart set, however, all were comparable in style and were normed for speed of picture-naming (Szekely, D'Amico, Devescovi, Federmeier, Herron, Iyer, Jacobsen, Arévalo, Vargha, & Bates, E., 2005). The full set of pictures included over 384 line-drawings, with an

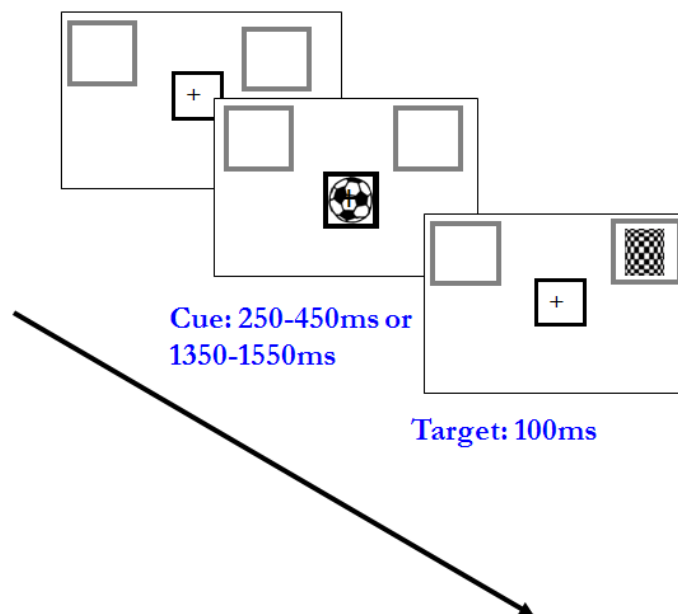
average size of $8^\circ \times 8^\circ$. Target stimuli consisted of black and white, checkerboard patterned, vertically-oriented rectangles.

In a sound attenuated room, participants viewed the stimuli on a 17-inch computer monitor. A commercial software package (“Presentation”; Neurobehavioral Systems; San Francisco, CA) was used to present stimuli and record responses. The stimuli were presented one at a time and in a random order, for 1000 msec each, separated by a 2000 msec interstimulus interval. Each encoding block required participants to make a different judgment about the pictures: (1) “Is the object heavy or light?” (2) “Does the object belong inside or outside?” (3) “Do you own the object?”. Thirty-eight objects were studied in this way: thirty-two of which were used in the subsequent test phase of experiment (the same thirty-two for all subjects).

After completing the encoding blocks, participants performed a continuous performance task (Please see figure below.). Participants were required to maintain fixation upon a centrally located cross throughout each block of trials. The background display consisted of a central fixation cross and two light gray square outline boxes, one located in the upper left visual field, and the other located in the upper right visual field. The non-predictive cue stimulus consisted of a black and white line-drawing presented at the fixation cross, and its duration varied randomly between 250-450ms and 1350-1550ms, with no inter-stimulus interval. The cue stimulus was either an “old” (previously studied) picture or a “new” (never before seen) picture. The ratio of old:new items presented was 0.33 (memory context = new). Targets appeared for 100ms, centered within one of the peripheral outline boxes. There were an equal number of targets in the left outline box and the right outline box. Again, all cue displays were non-predictive of upcoming targets. Participants were asked to

judge the side of the screen on which the target appeared (One button for left-hand side and another button for right-hand side). Participants were instructed to respond to the target as quickly as possible without sacrificing accuracy. (Note: originally a discrimination task was utilized in which participants had to judge whether a peripheral checkerboard was vertical or horizontal in orientation. However, pilot studies found no significant effects when this task was use; therefore, this task was replaced with a localization task.). Each participant completed a practice block, followed by 6 blocks of 64 trials each, for a total of 384 trials. Each block included a rest break at its midpoint.

DESIGN: EXPERIMENT 5



Results & Discussion

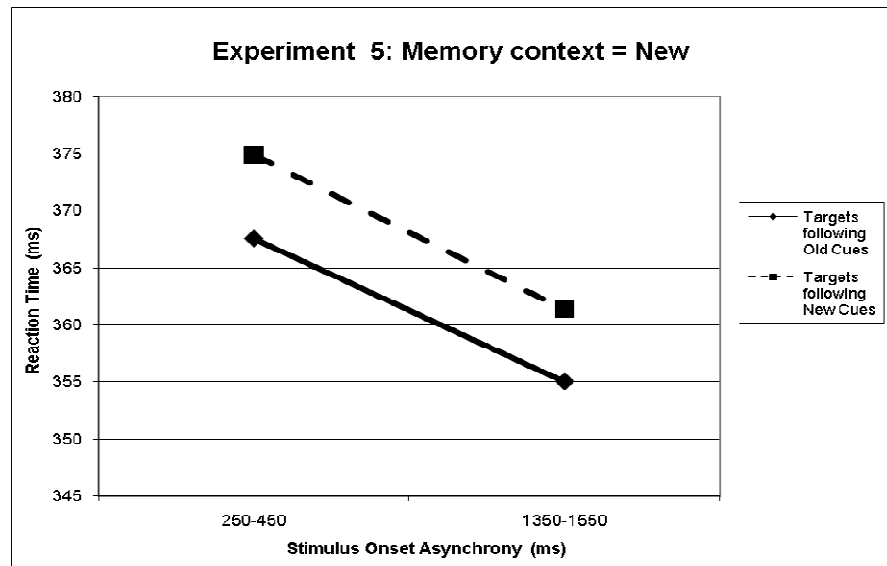
Participants identified 98.4% of cues as having the correct memory-status (old 98.2%; new 98.5%), and 99.3% of targets as occurring at the correct location (targets following old cues: 99.3%; targets following new cues: 99.3%). A two-way ANOVA was performed on the accuracy to the targets with the factors of memory-status (target followed by an old cue or a

new cue) and visual field (left or right). The ANOVA revealed no significant main effect of memory-status [$F(1,7)=0.005$, $p=0.944$], and no significant effect of visual field [$F(1,8)=0.451$, $p=0.523$]. The interaction between memory-status and visual field did not approach significance [$F(1,13)=0.020$, $p=0.892$].

A two-way ANOVA was also performed on reaction times to the target with the factors of memory-status (targets followed by an old cue or a new cue) and SOA (250-450 or 1350-1550). Only trials in which both the cue and the target task were correctly responded to were included in the analyses. The ANOVA revealed a significant main effect of memory-status [targets following old cue: 361.3; targets following new cues: 368.1; $F(1,7)=6.180$, $p=0.042$], as participants responded to targets more quickly when they were preceded by old cues as compared to new cues (Figure 5). This suggests that attention was held less by old memorially unique items. In addition, there was also a significant main effect of SOA [SOA 250-450: 371.2; SOA 1350-1550: 358.2; $F(1,7)=6.908$, $p=0.034$], as participants responded to targets more quickly when the cue-to-target SOA was longer. The interaction between memory-status and SOA did not approach significance [$F(1,7)=0.026$, $p=0.878$]. Because there was no interaction between memory and SOA, we chose to use both SOAs in a following pilot ERP experiment (mentioned above). However, this experiment (which did not include a cue task and is not included in this thesis) revealed few to none of the expected neural results. Upon inspection of the data, it appeared that the signal-to-noise ratio was not strong enough and that more trials would be needed to better interpret the data. In addition, we became concerned that the lack of a cue task may have led to the null effects found in this pilot experiment. Therefore, we chose to run a second ERP study (Experiment 6) using only one SOA; thus, doubling the number of trials in the experiment and increasing the signal-to-

noise ratio. Also, we added a cue task which forced participants to verbally state the memory-status of the memorial cue.

FIGURE 5: Reaction Times to Targets (Experiment 5)



After the cuing task, participants completed a recognition memory test for single objects (one-fourth new; one-fourth encountered in only the encoding phase; one-fourth encountered in the encoding and cuing phase; one-fourth encountered only during the cuing phase). Participants were asked whether or not they had studied the item during the encoding phase. Overall, participants correctly judged 100% of the studied items as “studied,” with no differences between items seen or not seen in the AB phase. [Studied Only: $M=1.00$ ($SD=0.000$); Studied & used in cuing phase: $M=1.000$ ($SD=0.000$); $t(7)=0.000$, $p=1.000$]. In addition, participants were highly accurate on judging items that were new as “not studied” ($M=96.296$; $SD=7.349$). These results suggest that the studied items were indeed deeply encoded by the participants.

Experiment 6

In Experiment 5 (and several pilot studies), participants were not required to respond to the memorial cue in any way, as we were interested in the automaticity of the effects of memory on attention. Following Experiment 5, we ran a pilot ERP experiment which was identical to the current Experiment 6, except that it did not include a memory cue task (and had one additional SOA range). This pilot experiment revealed no effects of memory on attention at the neural level. Therefore, the design for Experiment 6 was modified in two ways: (1) a task which required recognition of the memory-status of the cue was added, and (2) only one SOA range was used (1350-1550ms) to increase the signal-to-noise ratio. For further explanation, please see the Results section of Experiment 5. Before discussing the methodological details of Experiment 6, the predicted ERP effects to the memorial cues and the peripheral targets will be discussed below.

Hypotheses: Early Visual Components

Viewing the memorial cues will elicit early visual ERP components such as the P1 and the N1; however, it is hypothesized that there will be no differences in the amplitudes and latencies between “old” cues and “new” cues, as no memory-related effects have been found at this level of processing (around 100ms post-stimulus onset) (i.e. Woodruff, Hayama, & Rugg, 2006).

- 1) *The Parietal old/new effect:* As compared to new items, “old” items (that were deeply encoding during the study phase of the experiment) should produce a large positivity at parietal electrode sites around 500-800ms, replicating the parietal old/new effect.

The presence of this effect would provide evidence that successful recollection-driven recognition of these items had occurred during the cuing phase of the experiment. Behavioral measures should parallel this ERP result, finding that “old” items are correctly judged as being “previously studied” in an RKN memory test.

2) *The Early Context effect*: As compared to new (memorially non-unique) items, old (memorially unique items) should produce a greater positivity around 800-1100ms, replicating the early context effect found by Herron and colleagues. This finding might suggest that participants successfully maintained or updated a representation of the structure of the list, or in other words, that some sort of neural processing of the memorial context occurred.

3) *The Late Context effect*: As compared to new (memorially non-unique) items, old (memorially unique items) should produce a greater negativity around 1200-1600ms, replicating the late context effect also found by Herron and colleagues. Again, this would suggest that neural processing of the memorial context did take place. How (or if) this effect differs from the early context effect remains unclear. In the current paradigm, finding one context effect, but not the other (i.e. finding the early, but not the late; or the late, but not the early), may help to further differentiate the functions related to these ERP components.

Hypotheses: Predicted Behavioral & Neural Effects of Memory on Attention

Please note: previous results have demonstrated that the amplitude of the N1 is not influenced by attention during localization tasks, but is during discrimination tasks (e.g., Mangun & Hillyard, 1991; Vogel & Luck, 2000). Because our paradigm utilized a localization task, we do not expect to find any attentional effects (as modulated by memory) on the N1, and thus, the N1 is not discussed below.

- 1) *Early Visual Processing (the P1)*: If memorially unique (in this case, old) items hold attention longer than the non-unique items (as was demonstrated in the AB studies), then there will be a decrement in behavioral performance in the target task. Specifically, reaction times to targets following memorially unique items, as compared to non-unique items, will increase. In other words, the increased hold of attention on the unique item will cause participants to respond slower to following targets. Because the task related to the target will be a simple localization (i.e. Did the target appear on the left or on the right side of the screen?), we do not expect to see any significant differences in accuracy between targets following old versus new items. At the neural level, the decrement in behavioral (reaction time) performance would be manifested as reductions in early visual processing of the target; specifically, decreased amplitudes in the P1 to targets preceded by memorially unique items as compared to targets preceded by new memorially non-unique items. Such a finding would suggest that memorial unique items hold attention at the same level as voluntary and involuntary attention (i.e. at the P1).

In contrast, if memorially unique items (“old” in this case) do not hold attention in this paradigm (as occurred in Experiment 5), then reaction times to targets following memorially unique items will decrease as compared to reaction times to targets following new memorially non-unique items. In other words, there will be an enhancement in behavioral target performance to targets following unique (“old”) items (as indexed by reaction time measurements, but not accuracy measurements). It is hypothesized that such a behavioral effect would be accompanied with an enhancement of neural target processing. More specifically, we would expect to find increased amplitudes in the P1 to targets preceded by unique items as compared to targets preceded by common items. This result would provide evidence against the notion that attention is being held on memorial unique items in this paradigm. Instead, it would suggest that attention is more quickly disengaged from memorially unique items.

- 2) *Later Context Updating (the P300)*: It remains unclear how memory’s effect on attention will be reflected in the P300 to targets because all of the targets were equally salient and probable, despite being temporally linked to cues of variable salience and probability. Whether the salience and probability of the cues will be linked to the following targets is unknown.

Participants

Nineteen (9 females and 10 males) undergraduate students from the University of North Carolina at Chapel Hill were recruited to participate. Five participants were excluded

from data analysis due to excess movements, blinks, or other artifacts. Each participant was required to have 20/20 or corrected to 20/20 vision and no known neurological problems. Additionally, all participants were right handed. Each participant was paid \$30.00 as compensation.

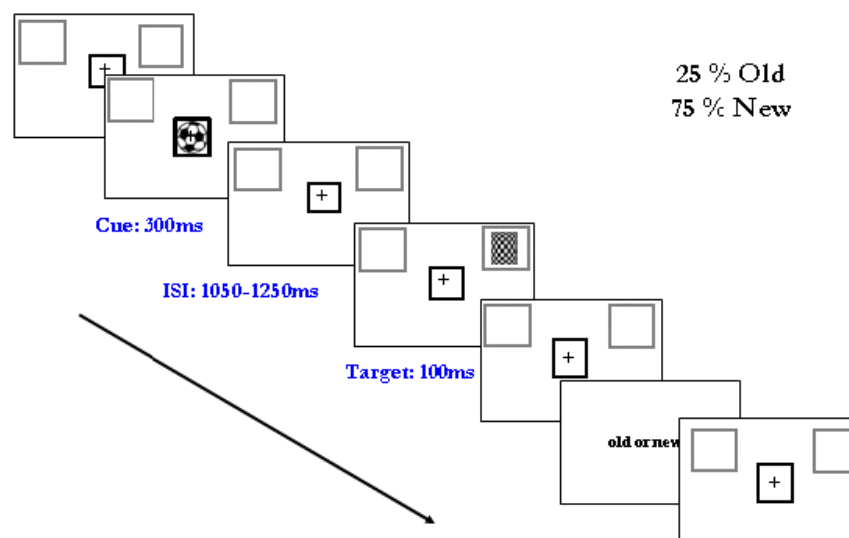
Materials & Procedure

Materials and procedures were identical to those used in Experiment 5, except that (1) participants also performed an old/new judgment on the cue item, and (2) the presentation timing of the stimuli was altered. In addition, ERPs were recorded as participants performed the test phase of the experiment.

After completing the encoding blocks, participants performed a continuous performance task (Please see figure below.). Participants were required to maintain fixation upon a centrally located cross throughout each block of trials. The background display consisted of a central fixation cross and two light gray square outline boxes, one located in the upper left visual field, and the other located in the upper right visual field. The non-predictive cue stimulus consisted of a black and white line-drawing presented at the fixation cross for 300ms. The cue stimulus was either an “old” (previously studied) picture or a “new” (never before seen) picture. The ratio of old:new items presented was 0.33 (old-unique condition). The stimulus onset asynchrony (SOA) between cue and target varied randomly between 1350-1550ms. Targets appeared for 100ms, centered within one of the peripheral outline boxes. There were an equal number of targets in the left outline box and the right outline box. All cue displays were non-predictive of upcoming targets. Participants were first asked to judge whether the central picture was old or new, and to hold their response until

further prompted. While remembering the memory-status of the cue, a peripheral target appeared, and participants judged the side of the screen on which the target appeared (One button for left-hand side and another button for right-hand side). Participants were instructed to respond to the target as quickly as possible without sacrificing accuracy. After responding to the target location, participants then responded as to whether the previous pictorial cue was “old” (previously studied) or “new” (never before seen). In contrast to the target task, the response to the cue was not speeded. Each participant completed a practice block, followed by 6 blocks of 64 trials each, for a total of 384 trials. Each block included a rest break at its midpoint.

DESIGN: EXPERIMENT 6



Recording & Analysis

EEG was recorded through the Active-Two Biosemi system from 96 electrode sites, amplified at a bandpass of 0.01-100 Hz, and digitized at 256 samples per second. Eye movements were observed throughout all runs via a closed-circuit infrared video camera, and the electrooculogram was recorded by electrodes located beneath both eyes and lateral to the

outer canthus of each eye. All trials containing eye-movements or blinks were rejected off-line and were not included in the analysis. Using the program Brain Electrical Source Imaging (BESA), EEG data was averaged to create ERPs, and the data was low-pass filtered to remove high frequency noise and high pass filtered with a single-pole causal filter to reduce low frequency drifts. The resulting ERP waveforms were then averaged across subjects referenced to the average signal from the electrodes located on the left and right mastoids.

Behavioral Results: the memorial cues

During the cuing phase of the experiment, participants identified 97.1% of cues as having the correct memory-status (old: 95.9%; new: 98.2%). In the recognition memory task after the cuing phase, participants correctly judged 98.2% of the studied items as “studied,” with no differences between items seen or not seen in the AB phase. [Studied Only: $M=0.976$ ($SD=6.052$); Studied & used in cuing phase: $M=.988$ ($SD=4.454$); $t(13)=-1.000$, $p=0.336$]. In addition, participants were highly accurate on judging items that were new as “not studied” ($M=92.857$; $SD=10.770$). These results, along with the high accuracy seen in memory task during the cuing phase, suggest that the studied items were indeed deeply encoded by the participants.

ERP Results: the memorial cues

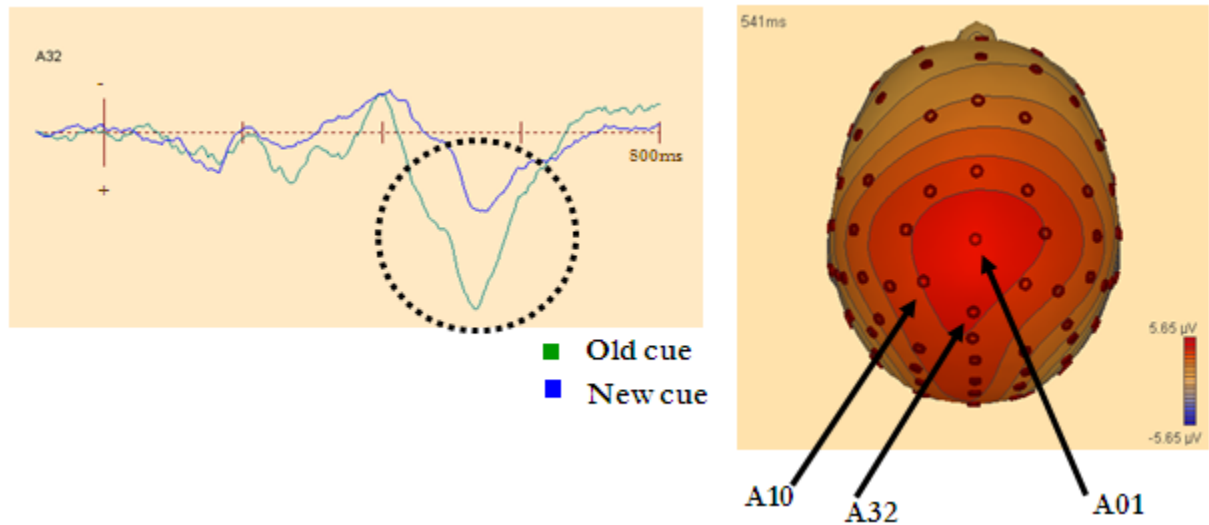
ERPs to the central memorial cue were examined for neural evidence of deep semantic encoding of the cue, and for memorial context updating of the cue within the test list. If participants deeply encoded the previously studied items (as was indicated by the

behavioral results), then the parietal old/new effect to these “old” items will be present. More specifically, the ERPs to previously studied items will be more positive than the ERPs to novel items beginning around 500ms in left parietal electrode sites. Further, if participants were updating the memorial context of the test item, as indexed by the early and late context effect, then ERPs to the memorially unique cue (in this case, “old” items) around 800-1100ms should be more positive (the early context effect) and around 1100-1550ms should be more negative (the late context effect). No effects should be seen at the sensory ERP components of these cues (around 100-200ms), as memory has not been found to affect such early stages of visual processing.

Analyses were conducted on the mean voltage amplitudes of the parietal old/new effect (523-542ms) and the late context effect (1100-1300ms) evoked by the memorial cue using a repeated-measures ANOVA. No early context effect was found; and thus, no statistical analysis was performed between 800 and 1100ms. Factors included memory-status (old cue vs. new cue) and electrode.

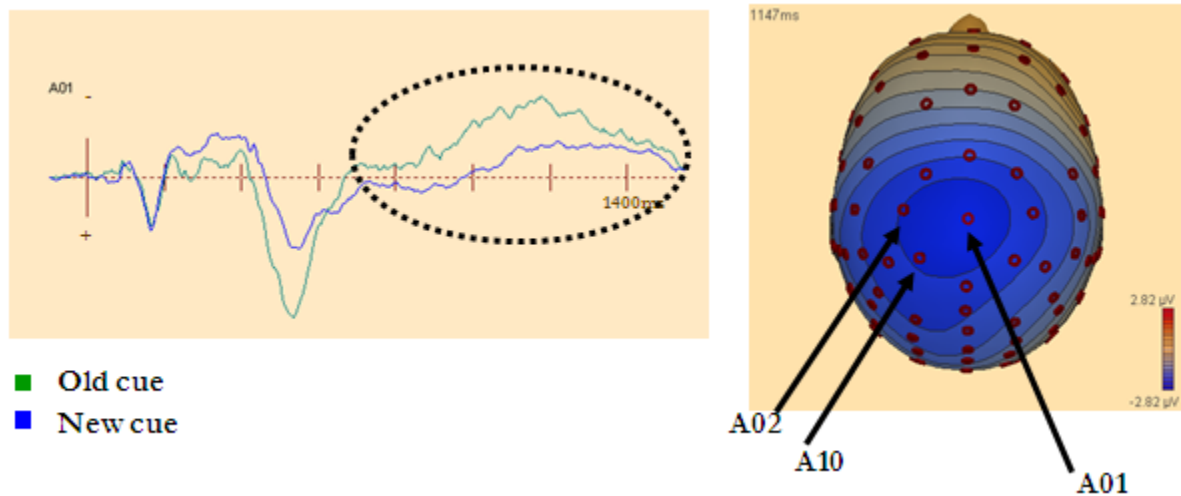
The parietal old/new effect. Between 523 and 542ms after cue onset, a significant main effect of memory-status was found [$F(1,13)= 500.970, p < 0.001$], as the old cues had a significantly larger parietal old/new effect as compared to the new cues. This finding replicated the parietal old/new effect and demonstrates that the old items were indeed recognized as previously studied at the neural level. There were no main effects of electrode [$F(2,26)= 2.895, p = 0.073$] (Please see Figure 6 for the exact electrodes selected for analysis.).

FIGURE 6: ERPs to Memorial Cues, the parietal old/new effect



The late context effect. In addition, analysis at the later time range (1100-1300ms) provided evidence that memorial context was maintained or updated at the neural level, as there was a significant effect of memory at this time range [$F(1,13)=15.681$, $p=0.002$]. Specifically, memorially unique items (in this case, old items) evoked a significantly more negative waveform between 1100 and 1300ms after stimulus onset as compared to the non-unique new items. There was also a significant effect of electrode, as the late context effect was stronger for left-central electrodes as compared to the central electrode [$F(2,26)=96.637$, $p<0.001$] (Please see Figure 7 for the exact electrodes selected for analysis.).

FIGURE 7: ERPs to Memorial Cues, the late context effect



Unlike the late context effect found by Herron and colleagues (which peaked at left prefrontal electrode sites), the late context effect found here peaked at central parietal electrodes sites, suggesting that the neural generator of this effect is relatively deep under the cortical surface or that some sort of coordinated neural activation is occurring during this effect. Additionally, a distinction was also found between the current result and those of Herron and colleagues. Specifically, the duration of the late context effect was decreased in the current experiment as compared to the effect found by Herron et al. This finding occurred in the time window in which the onset of the target stimulus occurred. Because the study by Herron et al did not contain any target stimuli, this may suggest that the presence of a target (or any other additional stimulus) may attenuate the late context effect. Further research manipulating the timing and presence of an interfering target is needed to confirm this hypothesis.

Discussion: the memorial cues

In summary, the analysis of the ERPs to the memorial cue suggests that the memory-status of the cue (as indexed by the parietal old/new effect) and the memorial context of the item list (as indexed by the late context effect) were both processed at the neural level. While the parietal old/new effect found here was very much in line with previous descriptions of this ERP component, the late context effect found here was slightly different. For example, the duration of the late context effect here was decreased as compared to Herron et al's effect, which suggests that the presence of the targets may have attenuated processing related to memorial context updating. In addition, it is currently unclear why no early context effect was found, but it is possible that its absence here was related to the presence of the peripheral target. Critically, the finding of a late context effect without an early context effect may suggest that these two components are sensitive to different cognitive functions or have different levels of susceptibility to interference. Further experiments manipulating the amount and timing of cue interference may help to dissociate the early and late context effects.

Behavioral Results: the peripheral targets

During the cuing phase of the experiment, participants identified 99.5% of targets as occurring at the correct location. A two-way ANOVA was performed on the accuracy to the target with the factors of memory-status (target followed by an old cue or a new cue) and visual field (left or right). The ANOVA revealed no significant main effect of memory-status [targets following old cue: 99.5%; targets following new cues: 99.5%; $F(1,13)=0.788$, $p=0.391$], and no significant effect of visual field [left: 99.7%; right: 99.4%; $F(1,13)=0.000$,

$p=0.999$]. The interaction between memory-status and visual field did not approach significance [$F(1,13)=0.071$, $p=0.793$].

A two-way ANOVA was performed on reaction times to the target with the factors of memory-status (targets followed by an old cue or a new cue) and visual field (left or right). Only trials in which both the cue and the target task were correctly responded to were included in the analyses. The ANOVA revealed a significant main effect of memory-status [targets following old cue: 363.336; targets following new cues: 384.578; $F(1,13)=33.873$, $p<0.001$], but there was no significant effect of visual field [left: 370.808; right: 377.106; $F(1,13)=0.499$, $p=0.492$]. The interaction between memory-status and visual field did not approach significance [$F(1,13)=0.731$, $p=0.408$]. Thus, like Experiment 5, participants responded faster to targets following old, memorial unique cues, regardless of the side on which the target appeared.

Critically, these behavioral results suggest that attention was *not* held by the memorially unique items (“old” here) in this experiment, as the reaction times to targets following old memorially unique items was decreased as compared to reaction times to new memorially non-unique items. In other words, an enhancement in behavioral target performance to targets following old memorially unique items was found. (This finding was different from the findings of Part 1 of this thesis, which demonstrated that memorially unique items held attention as indexed by an extended. Why this difference might have occurred will be addressed later in the discussion.) It was hypothesized that such a behavioral effect would be accompanied by an enhancement of neural target processing following old unique items, as evidenced by increased amplitudes in the P1 to these targets as compared to targets preceded by new memorially non-unique items. Based on previous

studies, we did not expect to see any effects on the N1 elicited by the targets. Lastly, it was unclear how memory's effect on attention would be reflected in the P300 to targets as all of the targets were equally salient and probable, despite being temporally linked to cues of variable salience and probability.

Before discussing the ERP results of Experiment 6, it is important to note that finding significant effects for reaction time measures does not necessarily suggest that significant effects will also be seen at the level of ERPs. Several studies have demonstrated dissociations between behavioral and ERP effects (Ries & Hopfinger, 2005; Hopfinger & West, 2006). For example, reaction time differences can be produced by multiple sources; and on the contrary, one ERP component can mask the effect of another ERP component, resulting in no apparent behavioral effect. In relation to the current study, the decrease in reaction time to targets following old memorially unique cues may or may not reflect changes with the corresponding ERP waveforms. However, investigations at the level of ERPs allows for a more clear understanding of the true mechanisms at work.

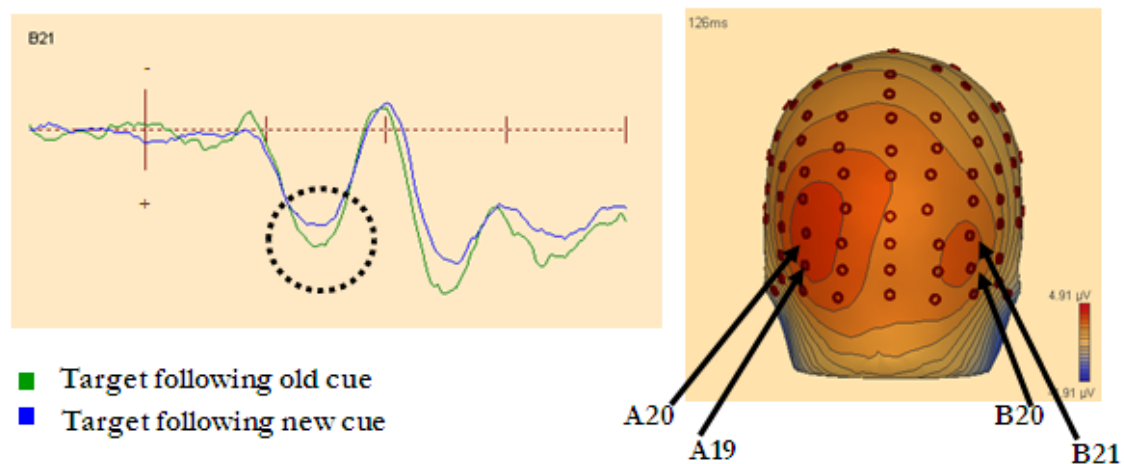
ERP Results & Discussion: the peripheral targets

ERPs to the peripheral targets were analyzed as a measure of attentional processing. In particular, we were interested in determining how the memory-status of the preceding cue would affect target processing. Analyses were conducted on the mean voltage amplitudes of the P1 (133-143ms) and the P300 (245-265ms) evoked by the peripheral targets using a repeated-measures ANOVA. Factors included memory-status (targets following an old cue vs. targets following a new cue), visual field (left vs. right), and electrode (*P1*: lateral vs.

more medial contralateral occipital locations; *P300*: anterior vs. posterior). Electrodes selected at the maxima of each ERP component can be seen in the Figures 9 and 10.

P1. Between 133ms and 143ms after target onset, a significant main effect of memory-status was found [$F(1,13)= 12.820, p = 0.003$], as the targets following old cues had a significantly larger P1 as compared to the targets following new cues. This finding provides evidence that the attentional processing of targets was enhanced for targets following memorially unique old items as compared to targets following new memorially non-unique cues. In addition, a significant effect of visual field was found as the P1 was stronger for targets located on the left than for targets located on the right [$F(1,13)=12.580, p = 0.004$] (Figure 8).

FIGURE 8: ERPs to Peripheral Targets, the P1

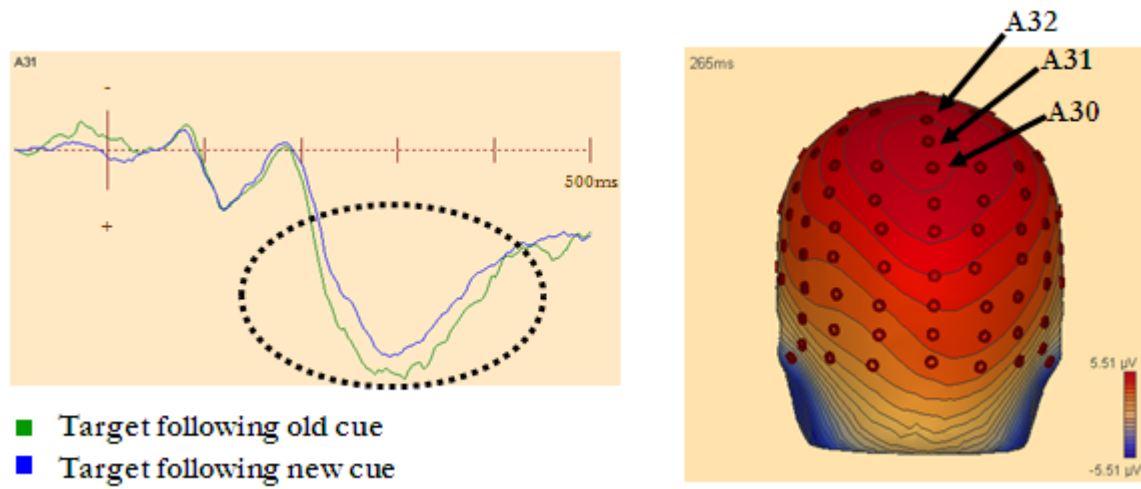


The P1 enhancement seen for some targets suggests that the memory items may act as orienting cues, which broadly shift attention to the upper visual field (where the targets are known to appear). When the target appears, attention is already shifted close to the possible

target locations; and thus, attention can affect target processing at an early stage of visual processing (i.e. the P1). If attention was not already shifted near the possible target locations (in other words, if the memory item was not an effective orienting cue), then attention would not be able to affect target processing at such an early stage of processing, as this processing would already be complete by the time attention was shifted to the target location. In summary, the increased disengagement of attention on old memorially unique items allowed attention to be more quickly allocated to possible target locations, which then led to early visual processing enhancements at the level of the target P1. If there was only one possible target location, then we would expect this P1 enhancement effect to be even larger as attention could be easily shifted to the appropriate target location.

P300. Between 245 and 265ms post target onset, a significant main effect of memory-status was found [$F(1,13)= 10.611, p = 0.006$], as targets following old cues had a significantly larger P300 as compared to the targets following new cues. In addition to the effect of memory-status, a significant effect of visual field was found as the P300 was stronger for targets on the left than for targets on the right [$F(1,13)=20.033, p = 0.001$]; however, no significant interaction was found between visual field and memory-status [$F(2,26)=1.126, p = 0.288$]. Lastly, there was no significant effect of electrode [$F(2,26)=1.126, p = 0.340$], nor an interaction between visual field, memory, and electrode [$F(2,26)=0.448, p = 0.644$] (Figure 9).

FIGURE 9: ERPs to Peripheral Targets, the P300



The above findings (in conjunction with the behavioral results) suggest that old memorially unique cues allow for a faster disengagement of attention (a decreased hold of attention), which then leads to an enhancement of early visual target processing (i.e. P1 amplitude increases to target following old items). How this effect is related to the P300 enhancement also seen for targets is unclear. Previous studies have found that the amplitude of the P300 is increased for items that are less probable and for items that are considered highly salient or ‘important’ to the task at hand (Donchin & Coles, 1988); however, the targets here were of equal probability (for left versus right locations) and of equal salience. There are two possible mechanisms, a direct and an indirect mechanism, which could be underlying the current ERP effect (increased P300 amplitudes for targets following old unique items). The direct mechanism suggests that each cue and target, being temporally close, become directly paired as one cognitive event. Although the targets are equally probable, the cue-target pairings are not. More specifically, targets following old cues are

more rare than targets following new cues (or in other words, an “old-cue-target” pairing is more rare than a “new-cue-target” pairing); and thus, the P300 is larger for these rare events in which targets are linked to a rare cue. While this hypothesis is possible, it seems less likely given that no P300 effect was found for the memorially unique (rare) cue. Another explanation lies in an indirect mechanism linking the cue and target. Again, recall that old memorially unique cues allowed for a faster disengagement of attention, which then led to an enhancement of early visual target processing (increased P1 amplitudes) to target following old cues. The fact that old memorially unique cues were more rare than the new memorially non-unique cues suggests that the P1 enhancement following these old unique cues was also a rare event. The rarity of this P1 enhancement could have led to an increased P300 amplitude for these targets (specifically, targets following old memorially unique cues). To test this hypothesis, the physical salience of the targets (i.e. the actual brightness of the stimulus) could be manipulated, in essence, making a subset of the target items more rare based on increased enhanced visual processing (in this case, due to a physical characteristic rather than an attentional enhancement). If bright unique targets lead to an enhanced P300, then this indirect mechanism would be supported. However, if no P300 enhancement is seen, then the direct mechanism described above may be a more accurate explanation for the P300 effect seen here.

In summary, analysis of the ERPs to the peripheral targets suggests that memory significantly affects target processing at early (the P1) and late (the P300) stages of analysis. In other words, the effect of memory on attentional allocation is not limited to higher order stages of conflict, but also affects the earliest stages of processing typically found to be modulated by attention.

CHAPTER 5

GENERAL DISCUSSION

The goal of Part 2 was to investigate the neural effects of memory, and particularly memory context, on attention. This was accomplished through the use of ERPs, with a manipulation of a classic cuing paradigm. Specifically, the voluntary arrow cue typically used in this paradigm was replaced with pictures of items which varied in their memory-status, referred to as “memorial cues”. We manipulated not only the memory-status of the cue, but also the memory context of the test list (in other words, the ratio of old:new items). By examining the ERPs to these memorial cues, we were able to determine the level at which these items were processed (i.e. whether they were deeply encoded and/or whether memorial context was processed). Critically, we were not only interested in the neural processing of cues, but also in the neural processing of targets following these cues. Of particular interest was how memory would affect target processing that is typically shown to be enhanced by attention (i.e. the P1 and the P300). The examination of target-evoked ERPs allowed us to determine if and how item-memory and memory context affect attention at the neural level. Importantly, we were interested not in the capture of attention by memory (as the onset of either old or new item can be distracting), but rather in the hold of attention (or in other words, the timing of disengagement), which may be affected differently by item-memory and memory context.

Again, although the primary goal of the current study was to investigate how memory affects the allocation of attention (through examination of the ERPs to the *targets*), it is imperative to first discuss the level of memorial processing which was attained by the memorial items (through examination of the ERPs to the *cues*). Distinct sets of memory-related ERP components have been identified: one reflecting recollection-driven recognition (the parietal old/new effect) and two reflecting memorial context (components identified by Herron et al). Importantly, all of these components have been found in experimental paradigms using a slow presentation of individual test items. In contrast to these paradigms, the current paradigm used a faster presentation time for the memory cues, and additionally, the memory item was followed by a peripheral target (again, similar to a classic cuing paradigm). To our knowledge, no previous studies have investigated how memory components, such as the parietal old/new effect and the context effects, are influenced by the presence of an additional stimulus following a memory item.

Our results replicated the parietal old/new effect, finding that “old”, memorially unique items (as compared to “new,” non-unique items) produced a large positivity at parietal electrode sites beginning around 500ms. The presence of this component provides evidence that successful recollection-driven recognition of these items had occurred during the cuing phase of the experiment (as was also evidenced by the recognition memory post test). In addition, the late context effect was also replicated, as old memorially unique items elicited a greater negativity beginning around 1100ms, suggesting that neural processing of the memorial context (more specifically, the maintaining or updating of the representation of the list structure) also took place. Though the late context effect was replicated, it is important to note that no early context effect was found, potentially suggesting that the

presence of the target interrupted some of the memory context updating. To fully elucidate the functional differences between the early and late context effects further research is needed. In summary, analysis of the ERPs to the memorial cue demonstrated that both recollection-driven recognition and some form of memorial context updating were processed at the neural level.

While the findings related to cue processing were of interest, it was the neural processing of targets following these cues which allowed for the examination of the effects of memory on attention. This analysis provided new evidence that memory significantly affects target processing, as an enhancement in both behavioral and neural target processing was found for targets following memorially unique, old items as compared to memorially non-unique, new items. Specifically, participants responded faster to targets following old memorially unique cues (as compared to new memorially non-unique cues), and importantly, this behavioral effect was accompanied with enhanced neural processing to these targets as indexed by increased P1 and P300 amplitudes (No effects on the N1 were found, which was expected as the N1 is not modulated by attention in localization tasks.). Again, this data provides new evidence that memory affects attention at the neural level. Given the direction of the behavioral results (decreased reaction times to targets following old, memorially unique items), the enhancement of target processing was expected. In other words, because attention was held less by the old memorially unique cues, increased attentional resources may have been allocated to the following targets. However, the direction of these findings was somewhat surprising based on the results of the AB studies in Part 1. Specifically, Part 1 found that memorially unique items (whether old or new) held attention longer than memorially non-unique items as exhibited by an extended AB. However, Part 2 of this study

found that old memorially unique items did not hold attention in this paradigm, as reaction times to targets following old memorially unique items were decreased as compared to reaction times to new memorially non-unique items. Why this dissociation between Part 1 and Part 2 was found is unclear and will be discussed below. However, before addressing this issue, it is first imperative to discuss what mechanism(s) may have been driving the effects demonstrated in Part 2.

Again, Part 2 found that participants responded faster to targets following old memorially unique cues as compared to new memorially non-unique cues. Additionally, enhanced target processing (at the level of the P1 and the P300) was found for targets following old memorially unique cues. Currently, it remains unclear whether these results were driven by the “oldness” or the “memorial context” of the cues; thus, the attentional effects observed in target processing cannot be exclusively linked to either the parietal old/new effect or the late context effect elicited by the cues. In order to separate the effects of oldness from those of memorial context, the memorial context of Experiment 6 would need to be reversed, making “old” items the distractors instead of new items. Thus, “new” cues would now be unique relative to ongoing memory context, contrary to Experiment 6 where “old” items were unique. If the attentional effects observed in Experiment 6 were solely due to the memorial uniqueness of the cue, then the memorial context should reverse the target effect, and new items should now lead to decreased reaction times to the targets and enhanced attentional processing of these targets (Note: the parietal old/new effect would still be enhanced for the old items, but the late context effect would now be enhanced for new items.). Conversely, if the attentional effects were solely due to the “oldness” of the cues, then the memorial context should not matter, and old items should again lead to decreased

reaction times to the targets and enhanced neural processing of these targets. Whether such an effect of “oldness” is driven by differences in recognition processing times or differences in perceptual fluency would require further research. Additionally, if the effect here is driven by recognition (as might be implied by the presence of the parietal old/new effect), then further research would also be required to dissociate recollective-driven recognition (based on retrieval of contextual information) from familiarity-driven recognition (based on a sense of previous exposure without a contextual retrieval) (Yonelinas, 2002). Previous studies have shown that recollection and familiarity have qualitatively distinct neural systems (Yonelinas et al, 2001). While the “study phase” in all of the experiments described here was intended to create deep semantic encoding, and thus, to produce recollection-driven memory traces, it is likely that both recollective and familiarity memory traces were generated. Therefore, it remains unclear whether familiarity alone would influence attention in the same way as recollective-based memory. If the current effects are indeed found to be driven by oldness (and not memorial context), then an experimental manipulation of the level of processing during the study phase (i.e. deep semantic processing vs. shallow perceptual processing) may help dissociate the effects of recollection from those of familiarity on attention. In summary, without further experiments, it is difficult to determine if oldness (whether recollective or familiarity-based) or memorial context underlies the current effects.

Despite the uncertainty regarding which quality of the memorial cues leads to the current effects, the primary goal of Part 2 was to investigate the neural mechanisms underlying the effects of item-memory and memory context on attention. In its design, the cuing paradigm used in Part 2 was intended to provide a measure of attentional hold (also known as attentional dwell time) through analysis of the reactions times to targets. If old

memorially unique items held attention longer than new memorially non-unique items (as would be predicted based on the AB results of Part 1), then a decrement in target behavioral performance following these old memorially unique items was expected. Conversely, if new memorially non-unique items held attention longer than the memorially unique old items (as would *not* be predicted based on the AB results of Part 1), then an enhancement in target behavioral performance following these old memorially unique items was expected.

Ultimately, the latter effect was found, suggesting that attentional dwell time was decreased for old memorially unique items; and therefore, that attention was held less by these items.

This conclusion is based on the notion that the effect seen here is due to differences in the hold of attention, as was demonstrated by the AB studies in Part 1. However, in Part 2, alternative explanations exist. First, memory's effect on attention may not have been driven by differences in attentional hold, but rather by differences in general arousal levels to the memorial cues. Perhaps arousal to old memorially unique cues is increased as compared to arousal to new memorially non-unique cues. While this explanation is possible, it would be expected that arousal effects would cause enhancements at all levels of processing, including the N1 (Eason, Harter, and White, 1969). Because we found enhancements only at the P1 and P300, it is less likely that the effects found here are driven by changes in arousal level.

Additionally, recent work by Olofsson and colleagues reviewed forty years of ERP studies which manipulated valence and arousal. They found that arousal effects (distinct from valence) occur after 200ms (Olofsson et al, 2008; Codispoti et al, 2007; Olofsson and Polich, 2007); and thus, cannot explain the P1 effect (~100ms) found here. Again, this suggests that arousal is not causing the effects of memory on attention seen here.

Whatever the mechanism driving Part 2, it seems that this mechanism may be independent or different from that inherent in Part 1, as Part 1 found that *memorially unique* items (whether old or new) produced an increased attentional hold, while Part 2 found that *old- memorially-non-unique* items held attention. What underlies this difference remains unclear. Of particular note, however, is the disparity in the timing of stimuli used in Part 1 as compared to Part 2. In Part 1 (the AB), each stimulus was displayed for 176ms with an ISI of 52ms, whereas each stimulus in Part 2 (the cuing paradigm) was displayed for 300ms with a large ISI ranging from 1050-1250ms. This difference in timing may have highlighted distinct levels of memorial processing from Part 1 to Part 2. In Part 1, the effect of memory on attention was found to be specific to memorial uniqueness and seemed to reflect an early automatic or unconscious updating of memorial context. For the purposes of this paper, this early automatic memorial context updating will now be referred to as “fast-context-perception,” and will reflect the early intense focus of attentional resources which lead to an increased hold of attention on memorially unique items. Importantly, it is possible that the ERP effects found in Part 2 did not highlight this early fast-context-perception stage of processing, but instead, highlighted a later (potentially overlapping) stage driven not by automatic memorial context updating, but rather by an effortful “memory classification.” As the old items in Part 2 were also unique, this memory classification stage may reflect either the classification of an item’s individual memory-status (i.e. leading to a decreased hold on *old* items) or the memorial classification of an item as compared to the test list (i.e. leading to a decreased hold on *memorially unique* items). The memory-status recognition may parallel the parietal old/new ERP effect, and the memorial context updating may parallel the late context ERP effect. Whether driven by oldness or memorial context, the memory

classification stage appears to occur later in stimulus processing (as indexed by the onset of these ERPs) and to be more conscious in nature (as indexed by the need for a cue task).

To contrast the “fast-context-perception” stage with the context updating inherent in the “memory classification” stage, it may be useful to relate the current findings to previous work in social cognition examining neural pathways to the amygdala. More specifically, when viewing fearful faces, a ‘fast-pathway’ for emotional processing is activated through direct connections from the lateral geniculate nucleus to the amygdala. This pathway is considered to be automatic in nature, in that it is activated even when emotional stimuli are not consciously perceived; and thus, may reflect an unconscious early warning system (Whalen et al, 1998). Additionally, a second indirect pathway to the amygdala (through visual processing areas) has been found to reflect a slower, conscious perception of emotional stimulus processing. These two stages of emotional processing, distinct in their level of automaticity, may provide an interesting parallel to the “fast-context-perception” stage and the context updating in the “memory classification” stage. Perhaps the fast-context-perception is similar to the unconscious ‘fast-pathway’ to the amygdala in that it provides a first automatic pass of stimulus processing (i.e. “Does this item fit with the other items I’ve been viewing?”). In contrast, context updating of the memory classification stage may be similar to the effortful pathway to the amygdala which provides a conscious recognition of the memory context (i.e. “This item is old, but I have been seeing a lot of new items.”). In summary, like the processing of emotional stimuli, memory context updating may be divided into multiple stages which vary in their level of automaticity. However, before testing this hypothesis, it is first necessary to determine if memory context or memory-status is driving the memory classification stage. Critically, however, the current set of studies provides the

foundation necessary to determine the stimulus timing (i.e. the ISI between cues and targets) best suited to dissociate the stages of memorial processing.

In conclusion, the current study provides new evidence for an aspect of attention that has not been well understood - the influence of memory on attentional allocation. Across four behavioral experiments, we examined the influence of item-memory on attentional dwell time by using a modified version of the AB paradigm (Part 1). Our results revealed that the AB was significantly affected by memory-status (novel versus old), but critically this effect depended on the ongoing memory context (Parks & Hopfinger, 2008). To examine the neural effects of memory and memory context on attention, we then recorded ERPs while subjects performed a modified cuing paradigm (Part 2). Our results provided new evidence that memory significantly affects target processing, and that this effect occurs at early (as indexed by the P1) and late (as indexed by the P300) stages of analysis. Specifically, targets following old memorially unique cues showed increased visual processing and faster reaction times compared to targets following new memorially non-unique cues. The results of Part 2, in conjunction with those of Part 1, suggest that the effect of memory on attention may critically depend on the neural level at which an item is being processed (whether at a fast-context-perception stage or at a memory classification stage). Overall, these results provide the first evidence that memory affects attention at the neural level.

REFERENCES

- Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society. Series B. Methodological*, 57(1), 289-300.
- Berger, A., Henik, A., & Rafal, R. (2005). Competition between endogenous and exogenous orienting of visual attention. *Journal of Experimental Psychology: General*, 134, 207-221.
- Broadbent, D. E., & Broadbent, M. H. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics*, 42, 105-113.
- Chanon, V. M., & Hopfinger, J. B. (2008) Memory's grip on attention: The influence of item-memory on the allocation of attention. *Visual Cognition*.16 (2-3), 325-340.
- Cheal, M. L., & Lyon, D. R. (1991). Central and peripheral precuing of forced-choice discrimination. *The Quarterly Journal of Experimental Psychology*, 43A, 859-880.
- Christie, J., & Klein R. (1995). Familiarity and attention: Does what we know affect what we notice? *Memory & Cognition*, 2, 547-550.
- Chun, M., & Potter, M. (1995). A two-stage model for multiple target detection in rapid serial visual presentation. *Journal of Experimental Psychology: Human Perception & Performance*, 21, 109-27.
- Codispoti, M., Ferrari, V., Bradley, M.M., 2007. Repetition and event-related potentials: distinguishing early and late processes in affective picture perception. *Journal of Cognitive Neuroscience* 19, 577–586.
- Craik, F. I. M. & Tulving, E. (1975). Depth of processing and the retention of words in episodic memory. *Journal of Experimental Psychology: General*, 104(3), 268-294.
- de Fockert, J., Rees, G., Frith, C., & Lavie, N. (2001). The role of working memory in visual selective attention. *Science*, 291(5509), 1803-1806.
- Diliberto, K.A., Altarriba, J., & Neill, W. T. (2000). Novel popout and familiar popout in a brightness discrimination task. *Perception & Psychophysics*, 62(7), 1494-1500.
- Donchin, E., & Coles, M. G. H. (1988). Is the p300 component a manifestation of context updating, *Behavioral and Brain Sciences*, 11(3), 355-425.
- Eason, R., Harter, M., & White, C. (1969). Effects of attention and arousal on visually evoked cortical potentials and reaction time in man. *Physiology and Behavior*, 4, 283-289.

- Fox, E., Russo, R., Bowles, R., & Dutton, K. (2001). Do threatening stimuli draw or hold visual attention in subclinical anxiety? *Journal of Experimental Psychology: General*, 130, 681–700.
- Friedman, D., & Johnson, R. (2000). Event-related potential(erp) studies of memory encoding and retrieval: a selective review, *Microscopy Research and Technique*, 51(1), 6-28.
- Giesbrecht, B., & Di Lollo, V. (1998). Beyond the attentional blink: visual masking by object substitution. *Journal of Experimental Psychology: Human Perception & Performance*, 24(5), 1454-1466.
- Heinze, H. J., Mangun, G. R., Burchert, W., Hinrichs, H., Scholz, M., Munte, T. F., et al. (1994). Combined spatial and temporal imaging of brain activity during visual selective attention in humans, *Nature*, 372(6506), 543-546.
- Herron, J. E., Henson, R. N. A., & Rugg, M. D. (2004a). Probability effects on the neural correlates of retrieval success: an fmri study, *Neuroimage*, 21(1), 302-310.
- Herron, J. E., Quayle, A. H., & Rugg, M. D. (2003). Probability effects on event-related potential correlates of recognition memory, *Cognitive Brain Research*, 16(1), 66-73.
- Hopfinger, J. B., & Mangun, G. R. (1998). Reflexive attention modulates processing of visual stimuli in human extrastriate cortex, *Psychological Science*, 9(6), 441-446.
- Hopfinger, J. B., & Mangun, G. R. (2001). Tracking the influence of reflexive attention on sensory and cognitive processing, *Cognitive, Affective, & Behavioral Neuroscience*, 1(1), 56-65.
- Hopfinger, J. B., & Ries, A. J. (2005). Automatic versus contingent mechanisms of sensory-driven neural biasing and reflexive attention. *Journal of Cognitive Neuroscience*, 17(8), 1341-1352.
- Hopfinger, J. B., & West, V. M. (2006). Interactions between endogenous and exogenous attention on cortical visual processing, *Neuroimage*, 31(2), 774-789.
- Johnston, W. A., Hawley, K. J., Plewe, S. H., Elliott, J. M., & DeWitt, M. J. (1990). Attention capture by novel stimuli. *Journal of Experimental Psychology: General*, 119(4), 397-411.
- Jonides, J. (1981). Voluntary versus automatic control over the mind's eye. In J. Long and A. Baddeley (Eds.), *Attention & Performance IX* (pp. 187-203). Hillsdale, NJ: Erlbaum.
- Jolicœur, P., & Dell'Acqua, R. (1998). The Demonstration of Short-Term Consolidation. *Cognitive Psychology*, 36(2), 138-202.

- Kahn, I., Davachi, L., & Wagner, A. D. (2004). Functional-neuroanatomic correlates of recollection: implications for models of recognition memory, *Journal of Neuroscience*, 24(17), 4172.
- Keil, A., & Ihssen, N. (2004). Identification facilitation for emotionally arousing verbs during the attentional blink. *Emotion*, 4(1), 23-35.
- Langton, S. (1999). Reflexive visual orienting in response to the social attention of others. *Visual Cognition*, 6(5), 541-567.
- Mangun, G. R., & Hillyard, S. A. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human Perception and Performance*, 17(4), 1057-1074.
- Mangun, G.R. & Hillyard, S.A., 1995. Mechanisms and models of selective attention. In M.D. Rugg & G.H. Coles (Eds.). *Electrophysiology of the Mind: Event-Related Brain Potentials and Cognition*. (pp.40-85). New York, NY: Oxford University Press.
- Mangun, G. R., Hopfinger, J. B., Kussmaul, C. L., Fletcher, E. M., & Heinze, H. J. (1997). Covariations in erp and pet measures of spatial selective attention in human extrastriate visual cortex, *Human Brain Mapping*, 5(4), 273-279.
- Müller, H. J., & Rabbitt, P. M. (1989). Reflexive and voluntary orienting of attention: Time course of activation and resistance to interruption. *Journal Experimental Psychology: Human Perception & Performance*, 15, 315-330.
- Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General*, 130(3), 466-478.
- Olivers, C. N. L., & Nieuwenhuis, S. (2006). The beneficial effects of additional load, positive affect, and instruction on the attentional blink. *Journal Experimental Psychology: Human Perception & Performance*, 32(2), 364-379.
- Olofsson, J.K., Nordin, S., Sequeira, H., Polich, J., 2008. Affective picture processing: An integrative review of ERP findings. *Biol. Psychol.* 77, 247–265.
- Olofsson, J. K., & Polich, J. (2007). Affective visual event-related potentials: Arousal, repetition, and time-on-task. *Biological Psychology*, 75(1), 101-108.
- Olson, I., Chun, M., & Anderson, A. (2001). Effects of phonological length on the attentional blink for words. *Journal Experimental Psychology: Human Perception & Performance*, 27(5), 1116-1123.
- Parks, E. L., & Hopfinger, J. B. (2008) Hold it! Memory affects attentional dwell time. *Psychonomic Bulletin & Review*. 15(6) 1128-34.

- Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma, and D. Bouwhuis (Eds.), *Attention & Performance X* (pp. 531-556). Hillsdale, NJ: Erlbaum Associates.
- Raymond, J., Shapiro, K., & Arnell, K. (1992). Temporary suppression of visual processing in an RSVP task: an attentional blink? *Journal of Experimental Psychology: Human Perception & Performance*, 18(3), 849-60.
- Rugg, M. D., & Allan, K. (2000). Event-related potential studies of memory, *The Oxford handbook of memory*, 521-537.
- Rugg, M. D., & Coles, M. G. H. (1996). *Electrophysiology of mind: event-related brain potentials and cognition*. Oxford University Press.
- Rugg, M. D., & Curran, T. (2007). Event-related potentials and recognition memory, *Trends in Cognitive Sciences*, 11(6), 251-257.
- Rugg, M.D. Henson, R.N.A., 2002. Episodic memory retrieval: an (event-related) functional neuroimaging perspective. In: Parker, A.E., Wilding, E.L., Bussey, T. (Eds.), *The Cognitive Neuroscience of Memory Encoding and Retrieval*. Psychology Press, New York, pp. 3-37.
- Ryan, J. D., Althoff, R. R., Whithlow, S., & Cohen, N. J. (2000). Amnesia is a deficit in relational memory. *Psychological Science*, 2(6), 454-461.
- Smith, M. E. (1993). Neurophysiological manifestations of recollective experience during recognition memory judgments, *Journal of Cognitive Neuroscience*, 5(1), 1-13.
- Smith, S.D., Most, S.B., Newsome, L.A., & Zald, D.H. (2006). An emotion-induced attentional blink elicited by aversively conditioned stimuli. *Emotion*, 6, 523-527.
- Slotnick, S. D., & Schacter, D. L. (2004). A sensory signature that distinguishes true from false memories. *Nature Neuroscience*, 7(6), 664-672.
- Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: norms for name agreement, image agreement, familiarity, and visual complexity, *J Exp Psychol*, 6(2), 174-215.
- Szekely, A., D'Amico, S., Devescovi, A., Federmeier, K., Herron, D., Iyer, G., et al. (2005). Timed action and object naming, *Cortex*, 41(1), 7-26.
- Tulving, E., & Schacter, D.L. (1990). Priming and human memory systems. *Science*, 247 (4940), 301-306.

- Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception & Performance*, 24 (6), 1656-1674.
- Wagner, A. D., Shannon, B. J., Kahn, I., & Buckner, R. L. (2005). Parietal lobe contributions to episodic memory retrieval, *Trends in Cognitive Sciences*, 9(9), 445-453.
- Wang, Q., Cavanagh P., & Green, M. (1994). Familiarity and pop-out in visual search. *Perception & Psychophysics*, 56, 495-500.
- Whalen, P.J., Rauch, S.L., Etcoff, N.L., McInerney, S.C., Lee, M.B., Jenike. M.A.. 1998. Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. *J. Neurosci.* 18:411–18.
- Wheeler, M. E., & Buckner, R. L. (2003). Functional dissociation among components of remembering: control, perceived oldness, and content, *Journal of Neuroscience*, 23(9), 3869.
- Wilding, E. L., & Rugg, M. D. (1997). An event-related potential study of memory for words spoken aloud or heard, *Neuropsychologia*, 35(9), 1185-1195.
- Woldorff, M. G. (1993). Distortion of erp averages due to overlap from temporally adjacent erps: analysis and correction., *Psychophysiology*, 30(1), 98-119.
- Woodruff, C. C., Hayama, H. R., & Rugg, M. D. (2006). Electrophysiological dissociation of the neural correlates of recollection and familiarity. *Brain Research*, 1100(1), 125-135.
- Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language*, 46(3), 441-517.